MAGICC/SCENGEN BASED ASSESSMENT OF FUTURE SCENARIOS OF INDIAN ENERGY SOURCES IN THE CONTEXT OF GLOBAL WARMING

THESIS

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IN

PHYSICS

BY

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This is to certify that:

1. The present study entitled **'MAGICC/SCENGEN based assessment of future scenarios of Indian Energy Sources in the context of Global Warming'** conducted by **Ms. Mukti Sharma** has been done under the joint supervision of myself and Dr. Chhemendra Sharma of National Physical Laboratory, New Delhi.

2. To the best of my knowledge this thesis or part of it has not been submitted for the award of any degree, diploma, associateship, fellowship etc. of any university or institute.

Dated: September 19, 2008

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2. To the best of my knowledge this thesis or part of it has not been submitted for the award of any degree, diploma, associateship, fellowship etc. of any other university or institute.

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Mukti Sharma

(Mukti Sharma)

Dedicated to my Parents

List of Publications

(A) List of articles published:

1. Published an article entitled 'MAGICC/SCENGEN software: A Brief' in Physics Bulletin, Aligarh Physical Society, Department of Physics, Aligarh Muslim University, Aligarh, February 2008.

2. Published an article entitled 'A brief introduction to numerical weather prediction' in Physics Bulletin, Aligarh Physical Society, Department of Physics, Aligarh Muslim University, Aligarh, February 2006.

3. Published an article entitled 'Theory of Relativity' in Physics Bulletin, Aligarh Physical Society, Department of Physics, Aligarh Muslim University, Aligarh, February 2005.

(B) List of conferences/ seminars/ workshop attended:

1. Attended 'Inception Workshop on India's Second National Communication to the United Nations Framework Convention on Climate Change' held at India Habitat Centre, May 28, 2007, New Delhi.

2. First Prof. R. Ananthakrishnan Memorial Conference held at Indian Institute of Tropical Meteorology Pune, INDIA from 18-19 January 2005.

3. National Seminar on 'Geography in the 21st century- issues and challenges', Department of Geography, AMU, Aligarh, India, 1-2 May 2004.

4. 'National seminar on Energy and Environment' held in Anand Engineering College, 21-22 Dec.2001, Agra.

(C) List of SERC schools attended:

1. Successfully attended and completed 'Second SERC School on Numerical Weather Prediction, Data Assimilation and Initialisation' held at IIT, Delhi, 2001 with 'Very Good' grade.

(D) List of papers presented at the conferences/ seminars:

1. Presented a paper entitled 'India's nuclear energy program and the extent of abatement in global warming and climate change during the present century' in

First Prof. R. Ananthakrishnan Memorial Conference held at Indian Institute of Tropical Meteorology Pune, INDIA from 18-19 January 2005.

2. Presented a paper entitled 'Enhanced Warming of the Polar Ice Caps and the attendant Sea Level rise effect – study of an extreme abatement scenario for CO_2 emissions to the atmosphere involving India' in National Seminar on 'Geography in the 21st century- issues and challenges', Department of Geography, AMU, Aligarh, India, 1-2 May 2004.

3. Presented a paper 'Global Warming and Climate Change' in 'National seminar on Energy and Environment' held in Anand Engineering College, 21-22 Dec.2001, Agra.

4. Presented a paper entitled 'MAGICC/SCENGEN based study of various parameters of Climate Change' in National Science Day celebrations held on 28 Feb. 2008, Department of Physics, Aligarh Muslim University, Aligarh.

5. Presented a paper entitled 'MAGICC/SCENGEN based prediction of future climate change using Indian emission scenarios' in National Science Day celebrations held on 28 Feb. 2006, Department of Physics, Aligarh Muslim University, Aligarh.

6. Presented a paper entitled 'Climate models based predictions of future climate change' in National Science Day celebrations held on 28 Feb. 2005, Department of Physics, Aligarh Muslim University, Aligarh and obtained consolation prize.

7. Presented a paper entitled 'Assessment of India's Nuclear Energy Programme in Combating Global Warming' in National Science Day celebrations held on 28 Feb. 2004, Department of Physics, Aligarh Muslim University, Aligarh.

(E) List of papers in journals:

1. Sharma, M., Sharma, C. and Qaiyum, A. Impacts of Future Indian Greenhouse Gas Emission Scenarios on MAGICC Model Outputs, Climate Change (submitted) 2008.

2. Sharma, M., Sharma, C. and Qaiyum, A. Impacts of Indian GHG Emission Scenarios on the SCENGEN Model Outputs of Temperature and Precipitation over Indian Region, Climate Change (submitted) 2008.

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Chapter 1

Introduction

Global change is a serious threat faced by the mankind in the present era. The major driver of global change is the changing climate due to anthropogenic activities. 'Climate' in a general sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant metrological parameters (like surface temperature, precipitation and wind) over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by World Meteorological Organization (WMO). According to Inter-governmental Panel on Climate Change (IPCC), the 'climate change' refers to a change in the state of 'climate' that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. 'Climate change' may be due to natural internal processes or external forcing, or due to persistent anthropogenic changes in the composition of the atmosphere or in land use. However, the United Nations Framework Convention on Climate Change (UNFCCC) defines 'climate change' as 'a change of climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere and which are in addition to natural climate variability observed over comparable periods (IPCC, 2007a). The difference between the IPCC and UNFCCC definitions of climate change is that the latter makes distinction between climate change attributed to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Over the last 150-200 years the change has been taking place too rapidly in Earth's atmosphere due to emissions of greenhouse gases (GHGs) from anthropogenic activities. This is considered to be the main reason of climate change. Climate change leading to global warming has now emerged as one of the most serious environmental concerns. It is a global phenomenon which has diverse local and regional impacts (IPCC, 2007b).

The changes in climate system have been quite pronounced in the rate and extent since the pre-industrial era due to the rise in the concentration of greenhouse gases in atmosphere. In the last 100 years (1906-2005), the Earth's surface and lowest part of the atmosphere have warmed up by an average of about 0.74°C ± 0.18°C (IPCC, 2007a). During this period, the amount of greenhouse gases, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), in the atmosphere has sharply increased largely as a result of the anthropogenic activities like consumption of the fossil fuels for energy and transportation, land use changes, agriculture, deforestation etc., for meeting the needs of growing population and economic development. The importance of greenhouse gases in the atmosphere lies in the fact that they act like a blanket around the planet Earth and trap the reradiated energy from the Earth's surface and consequently warm the atmosphere (i.e. greenhouse effect). If GHG concentrations in atmosphere are too high, excessive warming can distort natural patterns of climate. The natural greenhouse effect keeps the planet Earth and its biosphere at an adequate temperature for planetary processes to operate (IPCC, 2007a; UNFCCC, 2007).

The increased GHG concentrations in the Earth's atmosphere has led to disastrous consequences to the Earth system processes, which include rise in global mean surface air temperature (known as global warming), rise in global mean sea level posing a serious threat to low-lying coastal areas, increase in the extremes of climate events (like droughts, floods, cyclones etc.), increased epidemic of infectious and vector borne diseases such as malaria, dengue etc. and mass extinction of various plants and animal species. While the natural causes of climate change, including changes in the amount of energy coming from the Sun and shifting patterns of ocean circulations can cause global climate to change over similar periods of time, the balance of evidence now indicates that there is a discernible human influence on the global climate system (IPCC, 2007a). This influence, since the pre-industrial era has certainly led to the warming of the Earth, with a radiative forcing of +1.6 Wm^{-2} (range +0.6 to +2.4 Wm^{-2}). The impacts of climate change are not expected to slow down for decades even if the concentrations of the greenhouse gases get stabilized at present level (Arnell et al., 2002; Friedlingstein and Solomon, 2005; Meehl, et al., 2005; Wigley, 2005).

In order to take informed decisions on the mitigation of GHG emissions, development of future emission scenarios, based on different trajectories of development in various sectors like energy, industry, services, land use change and forestry etc. are also undertaken (IPCC, 2007c). One such effort is the preparation of Special Report on Emission Scenarios (SRES) by IPCC (SRES, 2000). Various global and regional models like Asia-Pacific Integrated Model (AIM) (Morita and Matsuoka, 1993; Matsuoka, 2000), Mini Climate Assessment Model (MiniCAM) (Edmonds et al., 1994, 1996a, b), Integrated Model to Assess the Greenhouse Effect (IMAGE) (Alcamo, 1994), Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) (Messner and Strubegger, 1995), Market Allocation Model (MARKAL) (Fishbone and Abilock, 1981; Fishbone et al., 1983), Atmospheric Stabilization Framework (ASF) ((Lashof and Tirpak, 1990; Pepper et al.,1998; Sankovski et al., 2000) etc. use these SRES scenarios as the important inputs in order to generate their respective outputs, both at regional and global basis. These models give the probabilistic outputs in terms of mean surface air temperature, mean rise in sea-level, changes in precipitation pattern etc.

Future of global climate depends on the choices of the development pathways which human society decides to follow in terms of economic, demographic, land use, agricultural, technological and energy profile changes. The interactions between these key-driving forces are very complex and are region specific. Based on these parameters, certain alternate futures have been developed for the whole globe, as well as for Indian region (Shukla et al., 2004). The four main classes of global scenarios developed by IPCC are A1, A2, B1 and B2 (SRES, 2000). Here, A1 family scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe *alternative directions of technological changes in the energy system*. The three A1 groups are further distinguished by their technological emphasis, for example fossil intensive

(A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The A2 scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other scenarios.

The B1 scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 scenario, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. The B2 scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Each SRES scenario family also contain two more types of scenarios--(a) those with harmonized assumptions about global population, economic growth, and final energy use and (b) those with alternative quantification of the storyline. So together, there are 26 harmonized scenarios adopting common assumptions on global population and gross domestic product (GDP) development. There are 14 other scenarios adopting additional scenario uncertainties beyond the differences in methodological approaches. On similar lines, region specific scenarios are also developed to provide a more realistic outlook for the particular region and the world as a whole.

Global climate change is perceived to be a problem that has been created mostly by industrialized nations, but its consequences are likely to be most adversely experienced in developing nations. Yet, despite growing recognition among experts and policymakers that developing countries are the most vulnerable to projected changes in climate, global-change research sorely lags behind in most of these countries (except for some emerging developing countries, including China, Brazil and India to some extent) and of the several hundred authors and contributors to the IPCC assessment reports, only 10 to 15 percent come from developing countries (Giorgi, 2001).

India's geographical location with its varied topography and demography gives it a unique importance concerning the impacts of climate change. It also is one of the fastest growing economy which has significant bearing on the future greenhouse gas concentration in the atmosphere. Although on the per capita basis, the present GHG emissions are much less than most of the developed countries but the growth rate of emissions are quite high (Sharma et al., 2006). However, India has already started directing its developmental goals keeping in view sustainable development in focus.

There is a need to pay adequate attention to the challenges of climate change to achieve sustainable development and create a better world. As per the recently released Fourth Assessment Report (AR4) of the IPCC, the atmospheric concentrations of CO_2 have increased from a pre-industrial value of about 280 ppmv (parts per million by volume) to 379 ppmv in 2005 exceeding the range observed over the last 650,000 years (180 to 300 ppmv) as determined from ice cores studies. The annual CO_2 concentration growth-rate was larger during the last 10 years (1995 – 2005 average: 1.9 ppmv per year), than it has been since the beginning of continuous direct atmospheric measurements (1960 – 2005 average: 1.4 ppmv per year) although there is year-to-year variability in growth rates. The primary source of the increased atmospheric concentration of CO_2 since the pre-industrial period is the fossil fuel use, with land use change providing another significant but smaller contribution. Annual fossil CO_2 emissions increased from an average of 6.4 GtC (i.e. 23.5 $GtCO_2$) per year in the 1990s, to 7.2 GtC (i.e. 26.4 $GtCO_2$) per year in 2000–2005 (IPCC, 2007a). CO_2 emissions associated with land-use change are estimated to be 1.6 GtC (i.e. 5.9 $GtCO_2$) per year over the 1990s, although these estimates have a large uncertainty (IPCC, 2007a).

The global atmospheric concentration of CH_4 has increased from a pre-industrial value of about 715 to 1774 ppbv in 2005 which far exceeds the natural range observed over the last 650,000 years (320 to 790 ppbv) as determined from ice cores. Growth rates have declined since the early 1990s, and the sum of anthropogenic and natural sources has been found to be nearly constant during this period. The global atmospheric N_2O concentration also has increased from a pre-industrial value of about 270 to 319 ppbv in 2005. However, the growth rate has been found to be approximately constant since 1980.

More than a third of all N_2O emissions are anthropogenic in origin and are primarily due to agriculture (IPCC, 2007a).

The increase in concentrations of GHGs leads to an increase of the atmospheric radiative forcing on the Earth which results in the increase in the global mean surface air temperature and cause global warming. The global warming causes rise in global mean sea-level and change in precipitation pattern. The combined radiative forcing due to increases in CO_2, CH_4 and N_2O has been estimated to be +2.3 Wm^{-2}. The rate of increase in the radiative forcing during the present era is very likely to have been unprecedented in more than last 10,000 years with carbon dioxide radiative forcing being increased by 20% from 1995 to 2005 (IPCC, 2007a). Anthropogenic contributions to aerosols produce a cooling effect, with a total direct radiative forcing of -0.5 Wm^{-2} and an indirect cloud albedo forcing of -0.7 Wm^{-2}. Other sources such as tropospheric ozone changes due to emissions of ozone-precursor gases like nitrogen oxides (NO_X), carbon monoxide (CO), and hydrocarbons (HC) etc. contribute +0.35 Wm^{-2} in the atmosphere. The direct radiative forcing due to changes in halocarbons is +0.34 Wm^{-2} in the atmospheric. Changes in surface albedo, due to land-cover changes and deposition of black carbon aerosols on snow, exert forcing of -0.2 Wm^{-2} and +0.1 Wm^{-2} respectively and changes in solar irradiance since 1750 are estimated to cause a radiative forcing of +0 12 Wm^{-2} (Houghton et al., 2001; Kaufmann and Stern, 1997; Kaufmann et. al., 2006; Schönwiese. 1994; Salinger, 2005a, b). This increase in radiative forcing has caused a 0.6°C rise in the average surface air temperature of the Earth over the past century and by about 0.2 to 0.3°C over the last 40 years. Also, even if the concentrations of greenhouse gases would be stabilized to various stabilization targets, which are being proposed, it would still take many decades to show any sign of reduction. Moreover, since Earth is covered largely by water, there is a time lag before atmospheric warming is seen to the expected degree. However, if CO_2 equivalent concentrations in the atmosphere stabilize between 450 and 1000 ppmv by 2100, the projected rise in global average surface temperature would be 2.1 to 5.5°C by 2100 (IPCC, 2007a). Moreover, rise in sea level and ice sheets is expected to continue in response to warming for many centuries even after greenhouse gas concentrations have been stabilized (Watson, 2001).

These changes are expected to drastically affect everyone's life on Earth with implications on food production, water supply, health, energy, forests, employment, intensity and frequency of extreme events, amount of precipitation, sea-level etc. Studies conducted by various research groups have predicted the various adverse impacts assuming there is no action to limit GHG emissions. Some of these impacts as provided by the IPCC AR4 reports (IPCC, 2007b) are as follows:

1. It is likely that all land areas particularly at northern high altitudes, warm more rapidly than the global average in the winter season. In contrast, the warming seems to be less in south and south-east Asia in summer and in South America in winter (Giambelluca and Sellers. 1996; Hare, 2005; IPCC, 2001b; Parry and Livermore 1999; Parry et. al., 2001; Zinyowera, Watson and Moss, 1998).
2. Higher maximum temperatures and more hot days are expected over nearly all land areas. The other expected impacts include likely occurrence of higher minimum temperatures, fewer cold days and frost days over nearly all land areas, reduced diurnal temperature range over most land areas. increase of heat index over land areas, more intense precipitation events, increased summer continental drying and associated risk of drought, increase in tropical cyclone peak wind intensities. increase in tropical cyclone mean and peak precipitation intensities (Bhaskaran and Mitchell, 1998; Easterling et al., 2000; Frich et al.. 2001; Gruza et al.. 1999; Groisman et al.. 1999; Hennessey et al., 1997; Haylock and Nicholls, 2000; Jones et al., 2000; Karl and Knight, 1998; Kunkel et al, 1999; Kharian and Zwiers, 2000; Michaels et al., 2000; Osborn et al., 2000; Sivakumar et al., 2005; Trenberth, 1998; Yamamoto and Sakurai, 1999).
3. A more *El Niño* like trend for surface temperature in the tropical Pacific is expected, with eastern tropical Pacific having an upper edge in warming than western one. Also a more intense *El Niño* is expected, than at present owing to the nonlinear relation between sea surface temperature (SST) and evaporation. The increase in the global average water vapour concentration and precipitation would affect water supplies and water quality, posing threats to hydropower, irrigation, fisheries and drinking water. Climate change is also likely to exacerbate water scarcity in Middle Eastern and African countries (Barnett et al., 2004; Frederick et al., 1997; Laevastu, 1993; Rosenzwig and Hillel, 1998; Salinger. 2005a,b; Timmermann et al., 1999).
4. Mass extinctions of various plant and animal species are also expected due to the rise in temperature. It is projected that warming of 0.8-1.7°C, 1.8-2.0°C and

>2.0°C would lead to extinction of 18%, 24% and >35% of species respectively (IPCC, 2001b; Norris and Rohl, 1999; IPCC 2007b).

5. Global mean sea level has also been projected to rise by 0.09 to 0.88 meters between 1990 and 2100, for the full range of SRES scenarios with areas at highest risk from sea level rise being those currently experiencing high erosion rates and those with very low elevations (Gosain et al., 2006; Nakicenovic and Stwart, 2000; Stive, 2004; Unnikrishnan, 2006; Zhang et al., 2004).
6. The summer flow of many rivers will be drastically decreased due to the absence of glaciers in the high mountains. It is projected that a local warming of larger than 3°C, if sustained for millennia, would lead to virtually a complete melting of the Greenland ice sheet with a resulting sea level rise of about 7 meters (Arnell, 1999, 2004; Eisma, 1995; Gosain et al., 2006; Kipasky et al., 2006; Leatherman et al., 2000; Nakicenovic et al., 2000; Stive, 2004; Unnikrishnan, 2006; Zhang et al., 2004).
7. Extreme climate events and climate variability are expected to become more intense (Folland et al., 1999; IPCC, 2001a; Meehl et al., 2000; Nicholls and Murray, 1999; Trenberth and Owen, 1999).
8. Forest damage from fire and diebacks driven by drought, insects and disease could increase (Maciver and Wheaton, 2005; Sivakumar et al., 2005; Easterling and Apps, 2005).
9. Climate change would result in an increase in the range of infectious and vector borne diseases, with likely increased risks of malaria and dengue (IPCC 2001a, b; IPCC 2007b; Bhattacharya et al., 2006).
10. Climate change also has direct and indirect impacts on energy use concerned with residential and building sector, agriculture, residential water demand and energy demand from transport sector (Kapshe et al, 2004; Polidano, 2000; Richards and tokes, 2004; Ravindranath et al 2006).

In order to mitigate the GHG emissions, various measures are being taken by the developed as well as the developing countries to save the planet Earth from the disastrous consequences of global warming. This includes creation of the IPCC, to marshal and assess scientific information on the subject. On 21 March 1994, UNFCCC was adopted which set an overall framework for IPCC to tackle climate Change with an ultimate objective '...to achieve stabilization of atmospheric concentrations of greenhouse gases at levels that would prevent dangerous anthropogenic (human-induced) interference with the climate system…'. Its principles hinge on equity and common but differentiated responsibilities, insistence of taking precautionary approach and not waiting for certainty so as to avoid the risk of being too late to avert the worst impacts and recognizes the balance between climate change, sustainable economic growth and development and importance of finding cost-effective measures to deliver global benefits at the lowest possible cost.

In compliance to these objectives, a series of measures like Berlin Mandate, Buenos Aires Plan of Action, Bonn agreements, Marrakesh Accords and protocols, such as Montreal Protocol, Kyoto Protocol etc. were adopted during last two or three decades. Of these, Kyoto Protocol (KP), adopted at third Conference Of Parties (COP 3) held at Kyoto, Japan, in December 1997 assumes great significance as it sets out the quantitative reduction targets for developed countries (i.e. Annex-I countries) (Dowlatabadi, 1999; Gerlagh and Zwan, 2004; Lempert and Schlesinger, 2000; Sims, 2003; Salinger, 2005a,b; UNFCCC, 2007).

Kyoto Protocol (KP) broke new ground with three innovative mechanisms – (i) Joint Implementation (JI), (ii) Clean Development Mechanism (CDM) and (iii) Emissions Trading (ET), which have been designed to boost the cost-effectiveness of climate change mitigation by opening ways for parties to cut emissions, or enhance carbon 'sinks' (more cheaply abroad than at home). Although the cost of limiting emissions or expanding removals varies greatly from region to region, the effect for the atmosphere is the same regardless where the action is taken. The protocol makes it mandatory for parties under Annex-I to reduce their annual average GHG emissions, namely CO_2, CH_4, N_2O and three industrial fluorochemicals, namely hydroflurocarbons (HFC), perflurocarbons (PFC) and sulphur hexaflouride (SF_6), in aggregate by 5.2% below their 1990 levels within the period 2008 and 2012 (the commitment period). Developing countries do not have any obligations for emission reduction under the KP (Babikar and Eckaus, 2000; Bate and Montgomery, 2004; Grubb et al., 2002 and UNFCCC, 2007).

JI allows Annex-I Parties to implement projects that reduce emissions, or increase removals using sinks, in other Annex-I countries. Emission reduction units (ERUs), generated by such projects, are then be used by investing Annex-I Parties to help meet their emission reduction targets. The CDM is expected to generate investment in developing countries, especially from the private sector, enhance the transfer of environmentally friendly technologies and promote sustainable development in general. The CDM allows Annex-I Parties to implement sustainable development project activities that reduce emissions in non-Annex-I Parties as well as helping non-Annex-I Parties to work towards sustainable development, and thus contribute to the ultimate objective of the Convention. The certified emission reductions generated by such projects can be used by Annex-I Parties to help meet their own emissions reduction targets (UNFCCC, 2007).

Various global and regional scenarios for the future have been developed based on the development policies adopted, and fed into the climate models, which include the multitude of factors taking part in the energy flow in the atmosphere, oceans, cryosphere, land surface and wildlife. The climate models also take into account energy transfer through the processes of convection, condensation, evaporation, reflection and radiation, besides emissions of GHGs due to anthropogenic activities to simulate the closest possible real picture. The results of climate models are then validated by the observed data sets and with those obtained from paleoclimatology. Basically, climate modeling is done to discern the responsibility of anthropogenic forcing for the global warming and to predict the future changes in the Earth's climatology.

The different climate models used for these purposes include simple one-dimensional models such as energy balance models, which simulate global radiation balance and the latitudinal energy transfer from the equator to poles, and radiative-convection models to simulate energy transfers through the atmosphere. Besides, there are two-dimensional statistical-dynamical models for simulation of the horizontal transfer of energy and the most complex three-dimensional General Circulation Models (GCMs) simulating the global scale processes including the landmasses, oceans and the atmosphere. The GCMs range from Atmosphere General Circulation Models (AGCMs), Ocean General Circulation Models (OGCMs), carbon cycle models, atmospheric chemistry models to coupled Atmosphere- Ocean General Circulation Models (AOGCMs). Also, there are Regional Climate Models (RCMs), which are better suited for regional predictions since they incorporate various local geographical features which greatly influence the local climate.

However, the simulations do have certain level of uncertainties but their importance lie in the fact that the future predictions of climate can be generated only through the use of these tools. So, the best course of action is to collate the results of a number of models (i.e. ensembles of model outputs) and not depend on any one particular model. Integrated models thus prove to be very useful in such circumstances and are being used extensively.

In the present study, MAGICC/SCENGEN 4.1 (**M**odel for the **A**ssessment of **G**reenhouse gas **I**nduced **C**limate **C**hange/**SCEN**ario **GEN**erator) code, originally developed at the Climatic Research Unit, University of East Anglia, Norwich, UK (Wigley and Raper, 1992, 2001, 2002; Wigley, 1993, 2000; Wigley et al., 2002) have been used to simulate parameters like temperature, precipitation, radiative forcing, GHG concentrations at global level for future scenarios for the year upto 2100 based on the default global emission scenarios as well as modified global emission scenario by incorporating the Indian emission scenarios. The simulated climate parameters for Indian region have also been extracted from the output results for the grids covering the Indian region.

India is the seventh largest country in the world in area, extending from 8°4′ to 37°6′ in the north and 68°7′ to 97°25′ in the east. It is bounded by the world's highest mountain-the Himalayas in the north and surrounded by Arabian Sea, the Indian Ocean and the Bay of Bengal in the south. The coastline, along the southern part of the country is over 7,500 km long. The country includes vast plains like the Indo-gangetic plains in north, and the central Deccan plateau in south which is bordered by the Western Ghats on either side in its west and south. India also has large desert plains in the western part and evergreen forests in eastern part. This huge diversity in the terrains leads to a wide variety of climatic conditions which ranges from permanent snowfields to tropical coastlands; areas of virtual desert in the northwest to fertile & intensively cultivated rice fields in the northeast.

The Indian climate system is basically dominated by the special wind system called monsoon. Westerly winds brings about 80% of annual rainfall in the months from June to October called the south-west monsoon and northerly winds are responsible for the north-east monsoon from December to February. Paleomonsoonal studies indicated a strong dependence of Indian climate system on monsoons (Cullen, 1981; Duplessy, 1982;

Dong et al., 1996; Nigam et al., 1992; Nigam, 1993; Pant and Maliekal, 1987; Pant et al., 1993; Prasad et al, 1997; Phadtare, 2000; Swaim et al., 1983; Sirocko et al.,1993; Thamban et al.,2001; Van Campo et al., 1982; Van Campo, 1986; Wasson et al., 1984). Monsoon is generally dominated by large-scale inter-annual variability and spatial contrasts which have a significant impact on basic resources like agriculture & water (Ashrit, 2001; Ashrit et. al., 2001; Kumar and Parikh, 1998; Kolli et al., 1992; Krishna Kumar et al., 1995; Chowdhary et al., 1989; Parathasarathy, 1984;). Generally, Indian monsoon is considered to be trend less (Mani, 1981; Rupa Kumar et al., 1992; Sontakke, 1993) but some researchers have succeeded in noticing a trend of monsoon over India (Rupa Kumar et al., 2002).

An increase of 0.4°C in mean annual surface air temperature per 100 years over India has been observed (Hingane, 1985; NATCOM, 2004). However, the all India surface air temperature during the drier part (January to May) of the year indicate a 0.3°C cooling during the last three decades (Krishna and Ramananthan, 2002). A general decrease in diurnal temperature variations has been observed for global (Alexandar et al.,2006) as well as Indian region (Kothawale and Kumar, 2005), predominantly due to an increase in maximum temperature (0.6°C/100yrs) and almost trend less minimum temperature (Rupa Kumar et al., 2006; NATCOM, 2004). Temperature records of upper air indicate a greenhouse gas associated cooling at upper stratosphere level and a warming at mesosphere level (Golitsyn et al., 1996; Kothawale and Rupa Kumar, 2005; Tyson et al., 2001).

Future projections of global mean surface temperature as per the IPCC AR4 estimates (IPCC, 2007a) for the six SRES emission marker scenarios reflect the best estimate for the low scenario B1 as 1.8°C (range 1.1°C - 2.9°C) and the best estimate for the high scenario A1FI as 4.0°C (range 2.4°C - 6.4°C).

With the rise in temperature and precipitation, the global sea level also is expected to rise. As per IPCC AR4, this rise in sea level would range from 0.18-0.38m for low scenario B1 and 2.4-6.4m for high scenario A1FI. The simulations also indicate a sharp rise in the extreme events (IPCC, 2007a). Studies indicate an increase of about 2.5mm/yr average sea level rise for India since 1950s, which could be disastrous to life and property (Patwardhan, 2006; Asthana, 1994; Das and Radhakrishna, 1991; IPCC, 1995; JNU, 1993; UNEP, 1989). As per the recent publication by Unnikrishnan, 2008, the sea-level in India has increased at a rate of about 1.3 mm/year for north India ocean. For Kolkata region, the sea-level has increased at a rate of about 5 mm/year due to combined reasons of sea level rise and subsidence. The average sea-level rise for India has been estimated to be close to 2 mm/year (Unnikrishnan, 2008).

For improving the quality of life of more than one billion people, India needs to plan and implement rapid economic growth in all sectors of the economy. In doing so, the availability of a reliable, efficient and adequate power infrastructure in the country is very crucial. The global electricity supply sector accounts for the release of over 7700 million tonnes of carbon dioxide annually (i.e. 2100 MtC/yr), which is 37.5% of total CO_2 emissions. Under business as usual conditions, the annual carbon emissions associated with electricity generation, including from combined heat and power cogeneration, is projected to surpass the 4000 MtC level by 2020 (IEA, 2004; Sims et al., 2003). The power sector in India relies primarily on the thermal generation of power using coal, which is available in large quantities in India. Therefore, in the business-as-usual scenario, emissions of CO_2 and other greenhouse gases from fossil fuel uses in India are bound to increase. India emitted a mere 3.0% of the world's total GHGs in1994 (Sharma et al., 2006). When measured on a per capita basis, Indian CO_2- equivalent GHG emissions in 2000 are much lower (1.5 tonnes/per capita) as compared to United States emissions (15.3 tonnes/per capita) and global average (3.9 tonnes/per capita) Sharma et al., 2006). The Indian per capita CO_2-equivalent GHG emission in 2030 is estimated to be 2.56 tonnes/per capita (Shukla et al., 2003). Estimates of CO_2 emissions from India from the burning of fossil fuels show that India's total CO_2 emissions is projected to grow considerably from 139 million tonnes in 1990 to 780 million tonnes in 2020 (ALGAS, 1998). However, total Indian GHG emissions have been projected to increase three-fold in 2020 from 1990 levels (Garg et al., 2004; IEA, 2004; Sharma et al., 2006).

At present, 70-72% of commercial energy is generated by using fossil fuels, mainly coal, and this scenario is expected to continue in the coming decades, posing environmental problems at the local, national, and global levels. Electricity consumption in India has more than doubled in the last decade, fueling the economic growth. Coal remains the mainstay of power generation providing about three-fifths of the country's total power. With 243.3 million tons of carbon (C) released from the consumption and flaring of fossil fuels in 1999, India ranked fifth in the world (Nair et al., 2003). India's energy-related carbon emissions have grown nine-fold over the past four decades and its contribution to world carbon is expected to increase in the coming years (Nair et al., 2003; EIA, 2002). The Indian GDP has grown at 5.7 percent per annum during the eighties, above 6 percent during the nineties and now hovering around 8-9% in recent years. Indian energy use has now grown faster than GDP for the last twenty years (GOI, 2000; CMIE, 2001).

Next to electricity generation, transportation is the other major sector utilizing oil and natural gas and contributing to GHG emissions. In India, a number of steps have been taken in this sector to make it more environmental friendly (Ramananthan and Parikh, 1999). These include introduction of lead free petrol for vehicles and use of CNG (Compressed Natural Gas) vehicles for public and private transportation (in cities like Delhi), introduction of EURO standard norms for vehicle emission control, implementation of auto-fuel policy etc. (Bate and Montgomery, 2004).

The commercial energy demand in India is growing at a high annual rate of over six percent (Shukla, 1996). The energy mix is dominated by use of coal, due to higher endowment of coal resources compared to oil and gas in the country (IEA, 2007; CMIE, 1997). This has led to a rapidly rising trend of energy related emissions (Loulou et al., 1997; Shukla, 1996). This trend, which is likely to continue, will enhance India's share in the global emissions in next few decades (Fisher-Vanden et al., 1997; Shukla, 1996). Emissions from large industries are growing at a higher rate than the national average (Schumacher and Sathaye, 1999a,b,c,d). Various studies have been undertaken to assess the efficiency and mitigation options of various industries like paper and pulp industry, aluminum industry, iron and steel industry (Schumacher and Sathaye, 1999a,b,c,d,e). The productivity trends and technological change in various energy intensive industries have also been studied for identifying the mitigation options to reduce the amount of carbon emitted into the atmosphere (Sari and Meyers, 1999; Meyers et al., 1989, 1999; Moreno and Sathaye, 1996; Mongia and Sathaye, 1998a,b; Meyers, 1998, 1999; Roy et al., 1999; Sathaye, 2000, 2001a,b, 2002; Vine and Sathaye, 1997).

Although most carbon emissions arise from use of coal in electric power generation and industry sectors, the sectors like agriculture and livestock emit substantial amounts of methane (Amol, et al., 2005; Meyers, 1998; Meyers et al., 1989; Sathaye et al., 1999; Sathaye et al., 2005; Tirpak et al., 1996). The India's Initial National

Communication to UNFCCC (NATCOM) has reported a net emission of 14.142 million tons of CO_2 for the year 1994 from the Land Use Land Use Change and Forestry (LULUCF) sector. The forestry sector offers great opportunity to sequester atmospheric CO_2 through natural regeneration, and afforestation on degraded forest areas and other waste lands (Makundi and Sathaye, 2003; Sathaye and Ravindranath, 1997, 1998; Sathaye et al., 2001a,b; Sathaye et al., 2005).

Emissions of greenhouse gases particularly the non-CO_2 gases such as methane (CH_4) and nitrous oxide (N_2O), from the agriculture sector are significant in India. The primary sources are the large agricultural areas under paddy cultivation, use of fertilizers and high cattle population in India (Schumacher and Sathaye, 1999e). Considerable research efforts and field experiments have been undertaken in India to understand the impacts of changes in the dietary pattern of cattle and agricultural management practices in rice paddy cultivation to reduce emissions of CH_4.

The industrial sector in India is estimated to contribute about 8.3% to the total CO_2 emissions from the country (NATCOM, 2004). 82% of the CO_2 emissions out of this are from cement, steel, bricks, and lime manufacturing, which are energy intensive processes. A study conducted by Development Alternatives (www.devalt.org) has shown that the present housing shortfall is over 30 million units, which is further growing. Natural resources like clay, slate and timber are in short supply, and the CO_2 emissions from brick-making, which are 17.75 million tonnes (with technology as usual) at present (i.e. 2000) can be reduced to 13.83 million tonnes using best current practices technology, and can be further reduced to 12.17 million tonnes using new technology. In 1990, the brick demand was 45.31 billion bricks, which has increased in 1998 to 55 billion bricks (Kumar et al., 1998) and further in 2000 to 61.20 billion bricks. This is projected to 73 and 89 billion bricks by 2010 and 2020, respectively. Therefore, by introducing new technology like the vertical shaft brick kiln (VSBK) (Lakshmikanthan, 1999), CO_2 emissions from brick making can be drastically brought down from an estimated 26 million tonnes of CO_2 to 15.3 million tonnes of CO_2 by 2020. This technological intervention reduces the consumption of fossil fuels drastically by as much as 60% (Schumacher and Sathaye, 1999a).

Besides CO_2, CH_4 and N_2O contributed 27% and 7% respectively to India's total CO_2 equivalent GHG emissions in 2000, the remaining being the CO_2 emissions.

Presently, agriculture and livestock related emissions contribute above 65% to Indian CH_4 emissions and above 90 % to N_2O emissions. Sulfur emissions have a slower growth rate since Indian fossil fuel has low sulfur contents (Garg et al. 2001a, b).

Indian energy system occupies a dominant position in South-Asian region with 85% share in the total commercial energy consumption in 2001. India's shares in the total installed electricity generation capacity and carbon emissions have been 82% and 86% respectively. The path of development chosen by India will greatly influence not only the country's energy and emission trajectories but also that of the region (DoE, 2001).

It has been observed that carbon emissions from China, which is already the second largest GHG emitter behind the United States, and India have risen steeply over the past decade. The Indian CO_2 emissions have increased by 33 percent between 1992 and 2002. As per the secretariat of the UNFCCC, India is among the top five GHG emitter countries in the world along with United States, China, Russia, and Japan (UNFCCC, 2007; Chandler, 2002).

The basic reason behind the rapid increase in CO_2 emissions from fast growing economies like India & China is the coal driven energy sector. Coal is by far the main source of energy for electricity generation. The relevance of coal has increased over time, particularly in low-income countries where the share of electricity generated by coal has shifted from 41% in 1990 to 46 % in 2003. In China, the use of coal has increased from 71% in 1990 to 79% in 2003. In India, the increment has been respectively from 65% to 68% for 1990 and 2003.

India is a developing country and needs to develop further to uplift it's ever increasing population from poverty and considers equity in per capita terms to be the basis of implementing any global abatement targets (Srivastava, 2006). Various carbon mitigation studies point towards a substitution of coal by gas, besides pushing energy efficient and low carbon technologies (Gabriele, 2004; Parikh and Parikh, 2002; Kriegler and Bruckner, 2004; Nair et al., 2003). However, a lot of steps such as improvement in energy efficiency through upgrading of currently employed technologies, introduction of advanced technologies that are more efficient or are based on renewable energy sources have already been under taken by the Government of India to reduce the emission intensities (Sathaye et al., 2006; Gabriele, 2004; Parikh and Parikh, 2002; Nair et al., 2003).

In view of the importance of Indian emissions in the global context, the present study aims to simulate climate scenarios for future using MAGICC/SCENGEN 4.1 model using the modified global GHG emission scenarios after incorporating Indian GHG emission scenarios developed based on **B**usiness-**A**s-**U**sual (BAU), **B**est **C**ase **S**cenario (BCS) and **Economy** (ECONOMY) approaches, the details of which are provided in chapter 3.

Chapter 2

Model: MAGICC/SCENGEN 4.1

The present study involves the simulations of GHG emission, GHG concentration, GHG radiative forcing and climate parameters like temperature, precipitation, sea-level rise etc. at global scale for future using the model, namely, MAGICC/SCENGEN 4.1 (Model for the Assessment of Greenhouse gas Induced Climate Change/ Scenario Generator). The codes for this model were developed at the Climatic Research Unit, University of East Anglia, Norwich, UK (Wigley and Raper, 1987, 1992, 2001, 2002; Wigley et al., 2002; IPCC 2001a,b,c). MAGICC gives the future projections of the atmospheric concentrations of the greenhouse gases (GHGs) besides other parameters like global mean temperature and sea level change etc. based on the input parameters that include global GHG emission inventories. The SCENGEN takes the outputs of MAGICC as its inputs and produces outputs at 5° latitude by 5° longitude grids. The outputs generated by SCENGEN include changes or absolute values of the temperature and precipitation, changes in or absolute values of temperature and precipitation variability, signal-to-noise ratios based on inter-model differences or temporal variability and probabilities of temperature and precipitation change above a specified threshold (Wigley, 2003).

2A. MAGICC Model

MAGICC assesses the greenhouse gas induced changes in climate such as changes in the GHG concentrations, radiative forcing of the GHGs (mainly CO_2, CH_4 and N_2O) and the corresponding changes in global mean surface temperature and global mean sea level. Besides these GHGs, MAGICC gives global mean time series for other reactive gases also such as CO (Carbon Monoxide), NO_x (Oxides of Nitrogen), VOCs (Volatile Organic

Components), the halocarbons such as HCFCs (**H**ydro**C**hloro**F**luroChloro **C**arbons), HFCs (**H**ydro**F**luro **C**arbons), PFCs (**P**er**F**luro **C**arbons) and SO_2 (Sulfur di**o**xide).

The simulations in MAGICC are carried out by a set of coupled gas-cycle, climate and ice-melt models which provide the outputs of global mean temperature and sea-level consequences of emission scenarios. The carbon cycle model of MAGICC 4.1 comprises an ocean section in which the atmosphere-to-ocean flux changes are represented as a convolution integral and a 5-box terrestrial biosphere model. Carbon cycle model gives a mathematical description of the fluxes of CO_2 between the various carbon reservoirs of the atmosphere, ocean and biota systems. It derives atmospheric CO_2 concentration changes from information on emission changes and exhibit great importance for calculating the changes in concentrations in response to new fluxes of CO_2 into the atmosphere, primarily those from the burning of fossil fuels and land use changes such as deforestation. The model carbon budget is given by

$$2.123\ d[\Delta]C/dt = E_{fossil} + D_n - S_{ocean} - S_{fert} \qquad (1)$$

Fossil emissions component (E_{fossil}), atmospheric buildup component and ocean flux components (S_{ocean}) are fixed, hence the net "deforestation" (D_n; i.e., net land-use-change emissions) and CO_2 fertilization (S_{fert}) need only be balanced (Wigley,1993.; Maier-Reimer and Hasselmann, 1987; Schimel et al., 1994; Wigley, 1991). Oxidation of fossil-derived CH_4 as an *in-situ* CO_2 source is also employed in MAGICC. The non-climate related uncertainties in carbon cycle model are examined by changing the mean value of the 1980s of net land-use change CO_2 emissions. A low value leads to a high concentration and vice-versa (Wigley, 1993, 2000). Methane (CH_4) model is a mass balance model of the form:

$$d[\Delta]C/dt = E/B - C/T - C/T_{soil} \qquad (2)$$

where B (= 2.75 $TgCH_4$/ppbv) is a concentration-to-mass conversion factor, T is the atmospheric lifetime and C/T_{soil} is a soil sink term (T_{soil} = 150 yr). Here, the atmospheric lifetime is considered to be a function of OH (hydroxide) concentration which depends on the concentrations of CH_4, CO, NOx and VOCs. Further, the model is fitted to atmospheric chemistry model inorder to determine the relative change in temperature

(Osborn and Wigley, 1994; Wigley et al.,2002; IPCC, 2001a). Nitrous oxide (N_2O) model is a simple mass balance model of the form:

$$d[\Delta]C/dt = E/[\beta] - C/T \qquad (3)$$

where [β] (= 4.81 TgN/ppbv) is a concentration-to-mass conversion factor. The lifetime T is assumed to be constant.

For the tropospheric ozone (O_3), chlorine loading method and bromine loading method has been employed (IPCC, 2001a; Wigley and Raper, 1992; Wigley, 1994). The halocarbon (CFCs) and sulfur hexafluoride (SF_6) models are simple mass balance models whose lifetimes are either constant or, for species that contain hydrogen in their molecular structure, may vary with the change in the OH levels in the atmosphere, paralleling changes in CH_4 lifetime. Climate feedback effects on the carbon cycle add to the total effects since the net effect of these feedbacks is positive, thus resulting in increased warming.

MAGICC considers four aspects of aerosol forcing, namely, direct aerosol forcing with a default value of –0.4 Wm^{-2}, indirect forcing with a default (mid) value of -0.8 Wm^{-2}; biospheric forcing component with the default value of -0.2 Wm^{-2} and fossil plus organic carbonaceous aerosol forcing (FOC) with a default value 0.1 Wm^{-2}. The default total forcing in 1990 has been considered as -1.3 Wm^{-2} from the range of -0.8 Wm^{-2} and -1.8 Wm^{-2}.

The climate sensitivity defines the equilibrium response of global-mean surface air temperature to a doubling of the atmospheric CO_2 concentrations. The default value of climate sensitivity (ΔT_{2x}) is 2.6°C and has been taken as such in the present study. In default mode, MAGICC runs each emission scenario three times through the climate model corresponding to three different values of climate sensitivity at 1.5°C, 2.6°C and 4.5°C respectively. Temperature changes and oceanic thermal expansion can also be determined by thermohaline circulation (THC) changes. For the default (varying THC) case, a moderate slow-down of the THC is considered as the globe warms, at the rate equal to the median of THC change results for seven AOGCMs whose results were used to calibrate MAGICC. Another factor called vertical diffusivity (K_z) is the speed with which oceanic mixing transport heat from the surface into the deeper ocean. This is another determinant of temperature change and oceanic thermal expansion. The default value for K_z is 2.3 cm^2/s, which correspond to the median value for effective diffusivity for the seven AOGCMs whose results were used to calibrate MAGICC. The oceanic thermal expansion, ice-melt and other water balance terms determine the sea level rise. There are also the non-expansion sea-level models used in MAGICC similar to the ones described in sea level chapter of TAR (Third Assessment Report) and AR4 (Fourth Assessment Report) of IPCC (IPCC 2001a, 2007a). In TAR and AR4, global mean temperature and sea level rise uncertainties were determined by simulating the results of seven AOGCMs (Cubasch and Meehl, 2001; Raper et al., 2001). MAGICC has been calibrated to match the temperature and expansion outputs for these seven models forced with 1% per year compound CO_2 changes. It is run for each of the seven parameters for all the full range of SRES emission scenarios (Nakicenovic and Stwart, 2000). The MAGICC model has the provisions to alter the parameters mentioned above for a better estimate of uncertainties.

MAGICC model derives the future global emission scenarios using default global emission values as well as any user-specified emission values. The present study involves development of India specific GHG emission values, which have been incorporated into the global emission scenario for generation of modified emission scenario to investigate the impacts of changing Indian emissions at global level in the twenty first century. The detailed methodology for development of Indian emission inventories have been discussed in the chapter 3.

MAGICC contains A1, A2, B1, B2 of SRES emissions scenarios (Nakicenovic and Stwart, 2000), and P50 scenario which is the median of all SRES scenarios besides WRE (Wigley, Reilly and Edmonds) and NFB (Non Feedback) scenarios from various models like AIM, MESSAGE, IMAGE, MINICAM and ASF. Present study also attempts to compare the differences between the outputs of MAGICC runs based on given (i.e., default) global parameters and the runs using modified emission scenario after incorporation of India specific emission values.

MAGICC also contains various model parameters, concerned with the uncertainties in the carbon cycle, the magnitude of sulfate aerosol forcing, the overall sensitivity of the global climate system to changes introduced by humans, ocean mixing rate and outputs of seven AOGCMs for warming and sea level projections. Moreover, in addition to the basic uncertainty ranges, calculated by default, uncertainty ranges for emission scenarios, for a user-specified set of model parameters are also calculated and the results of the two can be compared. This gives a better idea of influence of carbon cycle feedback, implications of the inclusion and exclusion of sulfate aerosols, responses to the changes in climate sensitivity and rate of thermohaline circulation. In the present study, the default values of the model parameters have been taken i.e., the study takes into account the effect due to carbon cycle climate feedbacks, mid value of carbon cycle model and mid value of aerosol forcing. For the climate model parameters, the thermohaline circulation has been taken as variable and the value of vertical diffusivity (K_z) is taken as 2.3 cm^2/s. For ice melt conditions, the mid value option in the code has been used.

The model outputs have been obtained for the concentrations of CO_2, CH_4 and N_2O, radiative forcing (RF) and mean global surface air temperature (ΔT) both for aerosol included and not included cases, as a mean of outputs of seven GCMs viz., GFDL (Geophysical Fluid Dynamics Laboratory), CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia), HadCM3 (Hadley Centre Climate Model 3), HadCM2 (Hadley Centre Climate Model 2), ECH4/OPYC (European Centre Hamburg 4), CSM (Climate System Model of NCAR) and PCM (Parallel Climate Model). While both the individual model output as well as the integrated output of the seven models can be obtained, present study has been focused on the integrated outputs, which are the average outputs of these models. The outputs of MAGICC model can be obtained for the twenty first century and beyond. Since the uncertainties are expected to be very high for the time period beyond 2100, in the present work, year 2100 has been taken as the end year for all the simulations.

The MAGICC is run by selecting a pair of emissions scenarios, which include no-climate-policy SRES scenarios, WRE CO_2 stabilization scenarios and the emission scenarios developed during the present study. Then a set of gas-cycle and climate model parameters is selected as described above. MAGICC simulation outputs then act as the inputs for the simulations of SCENGEN which produces regional as well as global outputs map for changes or absolute values of the temperature and precipitation, changes in or absolute values of temperature and precipitation variability, signal-to-noise ratios based on inter-model differences or temporal variability and probabilities of temperature and precipitation change above a specified threshold on 5° latitude by 5° longitude grid mesh.

2B. SCENGEN Model

SCENGEN is intrinsically a regionalization algorithm that uses pattern-scaling methods to produce climate and climate change information on 5° latitude by 5° longitude grids. Pattern-scaling methods are employed to create the climate change fields at 5° resolution, which can then be added to an observed 1961-90 baseline climate data set to obtain climate scenario values for the future time period. The regional results obtained are based on results from 17 coupled **A**tmosphere-**O**cean **G**eneral **C**irculation **M**odels (AOGCMs) namely, BMRC98, CCC199, CSI296, CSM_98, CCSR96, CERF98, ECH395, ECH498, GFDL90, GISS95, HAD295, HAD300, IAP_97, LMD_98, MRI_96, PCM_00 and WM_95 which can either be used individually or in any user-defined combination (Raper et al., 1996: Santer et al, 1990; Wigley and Raper 1992; Wigley 1993; Wigley and Raper 2001, 2002).

SCENGEN's baseline observed climate database includes the globally complete CMAP (**C**limate Prediction Center's **M**erged **A**nalysis of **P**recipitation; Xie and Arkin, 1997) precipitation and CRU (**C**limate **R**esearch **U**nit) temperature climatologies (New et al., 1999). The climate model data used in SCENGEN is from **C**limate **M**odel **I**ntercomparison **P**roject (CMIP) (Covey et al., 2003). SCENGEN contains a set of greenhouse gas-induced patterns of regional climate change obtained from 17 different AOGCM experiments and also sulfate aerosol-induced patterns of regional climate change obtained from a series of sulfate aerosol experiments performed by the University of Illinois at Urbana-Champaign GCM. Since the GCM experiments report results on different spatial grids, all GCM data have been interpolated onto a common 5° latitude/longitude grid. A geographically explicit climate change scenario was then created in SCENGEN by selecting a future time interval, a month or season, a variable (temperature or precipitation), and one or more of the AOGCMs in SCENGEN's library of model results. In the present study, outputs from all the AOGCMs have been generated with and without incorporating the aerosol effects for the parameters considered in the present study. The generated parameters include change values (% change in precipitation and change in temperature (°C) with respect to the base year 1990) as well as the actual values (sum of the modeled value which is the average of the 17 GCMs used in the SCENGEN model and the change in the climate parameters such as temperature and precipitation with respect to the base year 1990) in global mean surface air temperature, precipitation both annually as well as seasonally. The seasons are divided in four groups viz. DJF (December, January, Febuary), MAM (March, April, May), JJA (June, July, August) and SON (September, October, November). These outputs are generated for the years 2020, 2050 and 2100 using linear pattern scaling. For overcoming the spatial drift for Indian region 'Definition 2' method has been employed. The significance of choosing these years lies in the fact that these represent short, medium and long term future time scales. For generating simulations for the year 2020, the Indian emission inventories developed on the basis of the national development policies of India have been used. The Indian emission values are then extrapolated till the year 2050 for incorporation in modified global emission inventories used in the SCENGEN simulations and there after the Indian emission values were kept constant for the year 2100.

In SCENGEN, pattern scaling can be done by any of the two scaling methods, the standard linear method and a new power-law or 'exponential' scaling method. For exponential scaling method, the scaled percentage change 'A' for global-mean warming 'D' is

$$A = 100[(1 + a/100)^D - 1]$$

where, 'a' is the normalized percentage change at a grid point.

The problem of spatial drift in SCENGEN is overcome by employing two methods namely 'Definition 1' and 'Definition 2' where 'Definition 1' uses the difference between the start and end of a perturbation experiment while 'Definition 2' uses the difference between the perturbed state and the control climate at the same time. So, in case a model has any spatial drift (which most models do) then Definition 2 can remove this drift under the justifiable assumption that the drift is common to both the perturbed and control runs. The variability changes in SCENGEN are described in terms of ratios as

$$\text{Variability Change (\%)} = (F.S.D. / I.S.D.) - 1$$

Where, F.S.D. stands for Future Standard Deviation and I.S.D. for Initial (present-day) Standard Deviation. A zero value, therefore, represents no change while positive or negative values represent increase or decrease in variability respectively.

Area-average outputs for user-definable regions and for a library of thirty standard regions namely, global, land, ocean, NH (Northern Hemisphere), SH (Southern Hemisphere), Equ-Pac (Equator-Pacific), N3, N3.4, N4, USA (United States of America), Canada, Mexico, Brazil. Africa, Europe, India, China, Japan, AusNZ (Australia, New Zealand), C-Asia (Central-Asia), M-East (Middle-East), E-FSU (Eastern-Former Soviet Union), W-FSU (Western-Former Soviet Union), ROLA (Rest of Latin America), SEAsia (South East Asia), W-Pac (western-Pacific), Alaska, Grnlnd (Greenland), Antarc (Antarctica) and Arc-Is (Artic-Islands) can be obtained from SCENGEN. For the present study, area-average outputs for Indian region have been extracted from SCENGEN outputs. The primary purpose of the area-average results is to drive reduced-form impacts models in regions selected for their socioeconomic similarities. Area-average results for individual models are given first for the normalized greenhouse gas component of future climate change. These individual model results give the user a quantitative idea of inter-model differences at the regional scale. Along with these normalized area average results, spatial variability is also quantified model-by-model using spatial standard deviations. SCENGEN graphical user interface displays two or more maps at a time for comparison purposes. The model outputs are obtained for the pre-defined time period. In this present study, the time periods of 2020, 2050 and 2100 have been used, with year 2000 as the baseline year.

Model validation is done by comparing baseline model (control-run) data sets with the new observed climatologies. These validation results in SCENGEN are given in two ways: (i) via various overall comparison statistics (pattern correlations, root-mean-square errors, and mean errors) computed over the chosen region and (ii) through global error-field maps. For temperature, the error fields are defined as differences. For precipitation, the error fields are given as ratios (i.e., error divided by baseline and expressed as a percentage). Validation can be done for single model as well as for an average of all 17 models. The MAGICC/SCENGEN 4.1 model has been tested globally through various validation studies (Xie and Arkin, 1997; New et. al., 1999; Covey et al, 2003; Wigley et. al., 1998a,b; Santer et. al., 1999; Allen et. al., 2000; Santer et. al., 2000, Santer et. al., 2003 a,b, c; Smith et. al., 2003; Harvey and Wigley, 2003, 2006; Santer et. al., 2004; Wigley 2005a, b; Santer 2005; Glenckler et. al., 2006a,b; AchutaRao et. al., 2006; Hansen et. Al., 2006; Santer et. al., 2006a,b; Wigley et. al., 2006; Wigley, 2006). In the present study, the widely accepted MAGICC 4.1 has been used without any further validation studies.

In the present study, Indian region outputs, from seventeen models have been obtained for the changes in mean temperature and precipitation from the input of global emissions of greenhouse gases and aerosols viz. CO_2, CH_4, N_2O, NO_x, VOCs, CO, SO_2, CF_4, C_2F_6, HFC125, HFC134a, HFC143a, HFC227ea, HFC245ca and SF6. In the modified global emission inventories, India specific emissions of greenhouse gases such as CO_2, CH_4, and N_2O are only modified while the rest of the gases are taken as that of given in default database since Indian contribution to the rest is rather negligible in global totals.

Thus, the present study uses MAGICC/SCENGEN 4.1 model for simulating future global concentrations of greenhouse gases like CO_2, CH_4, N_2O, and other global parameters like radiative forcing (RF) and temperature change (ΔT) for 2020, 2050 and 2100 time periods using both default values for different parameters as provided in the model to get reference scenarios as well as by modifying the inputs for global values by using India specific emission estimates.

MAGICC/SCENGEN 4.1 code has been used since it contains the SRES emission scenarios from various models such as AIM, MESSAGE, IMAGE, MINICAM and ASF. The present study takes into account only the AIM model which involves the cooperative approach of that of several Asian country teams. AIM can also assess climate change policies, besides the assessment of related environmental problems such as air pollution, waste management, and water resources. Further, it facilitates detailed description of technologies and links to geographic information system to assess and present the distribution of impacts at local and global levels. Moreover, AIM includes various component models suited to assess macro-economic trends, energy and technology forecasts, ecosystem impacts and material balances and is very well acclaimed for providing detailed local and country level as well as global level assessments of international economic relationships and climate impacts.

In the present study, the results are obtained for the future concentrations of CO_2, CH_4 and N_2O; mean global surface air temperature both for aerosol included and not included cases, as a mean of seven GCMs viz., GFDL (Geophysical Fluid Dynamics Laboratory), CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia), HadCM3 (Hadley Centre Climate Model 3), HadCM2 (Hadley Centre Climate Model 2), ECH4/OPYC (European Centre Hamburg 4), CSM (Climate System Model of NCAR) and PCM (Parallel Climate Model).

In this study, three approaches namely (i) fuel mix BAU (Business-As-Usual) approach (ii) BCS (Best Case Scenario) approach and (iii) ECONOMY Sector approach, have been used to generate India specific emission estimates which have been incorporated in the default global emission inventories of reference scenario to develop modified scenarios. The details of this are provided in the chapter 3. These approaches are then used in A1, A2, B1, B2 and P50 approaches of the AIM model in the model library. This resulted in the generation of a total of 15 modified emission scenarios. Then, corresponding model results from the modified scenarios and the original default scenarios (as already present in the model library) have been compared to get comparative results for the assessment of changes in global mean surface temperature, sea level, precipitation and actual global mean surface temperature and precipitation also.

Chapter 3

Methodology: Preparation of Indian GHG Emission Inventory

There is growing evidence that human activity has already influenced climate and that this influence is likely to increase in the future (Hegerl et al., 1997; Kattenberg et al., 1996; Santer et al., 1996a,b,c; Tett et al., 1996). This prospect has produced an increasingly urgent demand for generation of various alternative futures or scenarios of climate change, incorporating the relationships between important drivers of resource availability, productivity and technological change capturing the understanding of both historical and current situation. Climate change scenarios, thus, help in the assessment of the future economic, ecological and social consequences (Watson et al., 1996). The increasing emissions of greenhouse gases into the atmosphere due to various human activities including generation and use of energy due to burning of fossil fuel, industrial activities, agriculture and land use changes are causing adverse impacts on ecosystem services (IPCC, 2007a,b).

India is a developing country with over a billion population. The quality of life in India can only be upgraded by strategic planning and implementation of policies for attaining rapid economic growth in all sectors of the economy. The energy sector is one of the key sector which catalyzes the rapid national economic growth. Consequently, energy sector is the largest contributor of GHG emissions also in India. During the 1994, energy sector GHG emissions have contributed to about 61% in the total Indian GHG emissions (NATCOM, 2004). The power sector in India relies heavily on the thermal generation of power using coal, it being an indigenous source. The rapid rise in the use of energy resources which is moving the country from a predominantly agrarian base to a sizable industrial base has further lead to increase in GHG emissions (Shukla et al., 2006).

In the coming years, India faces great challenges in the management of energy and environment. The path of development chosen by India, upon which lies the future growth of energy and emission trajectories, would be greatly influenced by technological developments both within and outside the country, economic cooperation between countries, and global cooperation in limiting greenhouse gas emissions (Nair et al., 2003). Carbon mitigation in India is complicated by the fact that India has large coal reserves, but limited gas and oil reserves. Various carbon mitigation studies point towards a substitution of coal by gas, besides pushing energy efficient and low carbon technologies (Kriegler and Bruckner, 2004). However, the substitution away from coal, therefore, would require energy imports.

In the present study, India specific emission inventories have been developed for incorporation into default GHG emission inventory for use in MAGICC/SCENGEN 4.1 model (IPCC 2001a; Wigley and Raper, 1987, 1992, 2001, 2002; Wigley, 1993, 2000, 2003; Wigley et al., 2002) to derive the future global scenarios. Different India specific GHG emission inventories have been developed for the period up to 2050, based on the information available regarding the securing energy security, sectoral growth rate etc. to investigate the impacts of likely Indian emissions on model MAGICC/SCENGEN 4.1 outputs for the time period till 2100. This model also contains P50, A1, A2, B1 and B2 of SRES (Special Report on Emission Scenario) emissions scenarios (Nakicenovic and Stwart, 2000), and takes inputs from other models like AIM, MESSAGE, IMAGE, MINICAM and ASF.

The various SRES scenarios are also discussed hereunder. The methodologies used for development of various India specific emission scenarios are described below:

3A. SRES Scenarios

SRES scenarios are the global scenarios which assume distinctly different storylines giving directions for future developments, in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change (Nakicenovic and Stwart, 2000).

3A.1 A1 scenario

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

3A.2 A2 scenario

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

3A.3 B1 scenario

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

3A.4 B2 scenario

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

3B. India Specific Emission Scenarios

In the present study, the MAGICC/SCENGEN 4.1 model has been used to derive future global concentrations of greenhouse gases like CO_2, CH_4, N_2O, and other parameters like radiative forcing (RF), precipitation and change in surface air temperature (ΔT) and sea-level rise using both default input values for different parameters provided in the model to get reference scenarios as well as by modifying the inputs for global values incorporating India specific emission estimates for the period 2000-2100. For the later case, three approaches namely (a) BAU (Business-As-Usual) approach, (b) BCS (Best Case Scenario) approach and (c) Economy Sector approach have been used to generate India specific GHG emission estimates as per the details provided below. Business-As-Usual (BAU) approach visualizes practicing present technology without any drastic improvement in infrastructure. Best Case Scenario (BCS) approach envisions intensified efforts to modernize power plants, improve transmission and distribution efficiency, and adopting more efficient generation technologies. Economy approach deals with the overall variation in GDP and captures the improving GDP due to the technological advancements being made. These three approaches bring out the total range of likely future Indian CO_2, CH_4 and N_2O emissions. These estimates of GHG emissions for India have been incorporated in the default global emission scenarios provided in the MAGICC/SCENGEN 4.1 model to develop modified global emission scenarios which then used to delineate the impacts of changing Indian emissions on the parameters of future global concentrations of GHGs, RF, ΔT, global sea-level and global precipitation. The details of these approaches are as provided below:

3B.1 Business-As-Usual (BAU) approach

This approach is based on the BAU approach of the Planning Commission of India (PC, 2002a) and India Vision 2020 document (PC, 2002b). The CO_2 emission inventory developed under this approach has its base on the estimated demand of coal, oil and natural gas in 2020, which is estimated to be respectively 688 Mt, 245 Mt and 70.8 billion cubic meters as reflected in 'vision 2020' document of Planning Commission of India (PC, 2002a). The actual coal consumption figures for the years 1990, 1994, 1995, 1997-2007 have been taken from different official documents of Government of India (CEA, 2005; IEA, 2006; NATCOM, 2004; ALGAS, 1998; CMIE, 2001; MoC, 2006-07 and ECS, 2006-07). On similar lines, The actual consumption for oil (petroleum) and gas (natural gas) for the years 1990, 1997, 2000-05 have been taken from the official documents of the Planning Commission and Ministry of Petroleum, Government of India (MoP, 2006-07). These numbers were then linearly extrapolated up till 2050 and there after kept constant until the period 2100, assuming a static demand for coal, oil and gas during 2050-2100 period as the additional power requirement beyond this period is considered to be met from the alternative cleaner sources of energy.

Based on the figures for coal, oil and gas demands, the inventory for CO_2 emissions was generated by calculating the carbon emission intensity of coal, oil (petroleum) and gas. The values related to the carbon emission intensity of coal (0.360 MtC /Mt of coal) have been taken from the available literature (Mittal and Sharma, 2004). Carbon emission intensity of oil (petroleum) (2.6 MtC/Mt of oil) and carbon emission intensity of gas (2.2 MtC/billion cubic meter) have been used from the database of Energy Information Administration (EIA), division of the Department of Energy (DOE) of United States of America (USA) (http://www.eia.doe.gov). From the carbon emission intensity factors of coal, oil and gas and their respective demands, the total carbon dioxide emissions from energy sector in India was calculated to be 0.454 PgC for the year 2000, 1.026 PgC for the year 2020 and 1.991 PgC respectively for the year 2050 (Table 1). From 2050 onwards, the carbon dioxide emission values are taken as constant till the year 2100. The carbon dioxide emissions resulting from deforestation has not been altered in the modified default scenarios as its contribution to the national total emission is minor (NATCOM, 2004).

For generation of future scenarios of CH_4 and N_2O emissions, Indian emission values for the years 1990, 1994, 1995, 2000 and 2005 have been taken from the available literature (ALGAS, 1998; Bhattacharya and Mitra, 2004; Garg et al., 2006 and NATCOM, 2004). These have been kept constant at 2020 value till 2100 assuming insignificant increases in the global CH_4 & N_2O emissions in future due to better and sustainable waste and farm management practices which are the major contributors of these emissions. Methane emissions for the years 2000 and 2005 were respectively taken to be 19.6 Tg and 20.1 Tg (Garg et al., 2006). Then the compounded annual growth rate (CAGR) for the period 2000-05 was calculated for CH_4 emissions which came out to be 0.47%. From this CAGR value, CH_4 emissions were calculated to be 20.6 Tg for the year 2010 and 21.5 Tg for the year 2020. Further for the period 2020-2100, CH_4 emissions were kept constant at 2020 value (Table 2). On similar lines, N_2O emissions for the years 2000 and 2005 were respectively taken to be 0.1 TgN and 0.2 TgN (Garg et al., 2006). Then the CAGR for the period 2000-05 was calculated for N_2O emissions which came out to be 3.12 %. From this CAGR value, N_2O emissions were calculated to be 0.2 TgN for the year 2010 and 0.3 TgN for the year 2020. Further for the period 2020-2100, N_2O emissions were kept constant at 2020 value (Table 3). Since, Indian CH_4 and N_2O emissions are small (i.e. 5% and 3% respectively) in the global CH_4 and N_2O emissions (ALGAS 1998), these percentages have been assumed to be same for future time period for global CH_4 and N_2O emissions (Tables 2 & 3). The computed estimates of CO_2, CH_4 and N_2O emissions, thus obtained, have been incorporated in the default global emission inventory to generate future global GHG emission scenarios.

3B.2 Best Case Scenario (BCS) approach

This approach is based on the BCS approach of the Indian Planning Commission (PC, 2002a) and India Vision 2020 document (PC, 2002b). Here, the CO_2 emission inventory has been generated based on the projected coal, oil and gas demands in India up-till the period of 2020, which is estimated to be 538 Mt, 195 Mt and 64.7 billion cubic meters respectively (PC, 2002a). The coal consumption in the years 1990, 1994, 1995, 1997 and 2000 (ALGAS, 1998; CMIE, 2001; CEA, 2005; ECS, 2006-07; IEA, 2006; MoP, 2006-07; MoC, 2006-07 and NATCOM, 2004) have been used to generate CO_2 emission inventory using the carbon emission intensities of coal, oil and gas. The carbon emission intensities of coal, oil and gas used are as mentioned earlier under the BAU approach.

The CO_2 emission inventory from coal, oil and gas consumptions for the period 2020-2050 has been generated assuming the similar growth ratio in coal, oil and gas demands as projected for the period 2000-2020. However, for the period beyond 2050, it has been kept constant assuming significant shift in energy production from coal based to clean fuels for meeting additional energy demands beyond 2050. Thus, for the BCS approach the CO_2 emission for the year 2000 comes out to be 0.454 PgC, for the year 2020, CO_2 emission came out to be 0.830 PgC and for the year 2050, CO_2 emission was found to be 1.386 PgC. Further, the 2050 value was kept constant till the year 2100 (Table 1). The CH_4 and N_2O emission inventories, as developed under BAU approach and discussed earlier, have been used under BCS approach also (Tables 2, 3).

3B.3 Economy Sector Approach

The estimations of CO_2 emissions in this approach are based on the Gross Domestic Product (GDP) of the Indian economy. It incorporates the actual trend of the GDP growth rates observed in different sectors of Indian economy for the 1990-2006 period as reflected by the official documents of the Government of India (PC, 2002b; ECS 2006-07).

Year 2007 denotes the end year of the ninth Five Year Plan of Government of India. For the tenth five year plan period (i.e. 2007-12), the GDP growth rate per annum has been targeted to be around 9% as per the by the planning commission of India (PC, 2002 a,b). For our calculations, we have assumed that this 9% growth rate will continue to be observed until the year 2020. However, for the period of 2020-2050, the growth rate has been assumed to be about 4%. For the period 2050-2100, the GDP (in crore rupees) has been taken as constant at 2050 value. This is based on the assumption that by 2050, the Indian economy will be adequately developed and thereafter GDP growth rate would be such so as to sustain the economic progress. The 4% growth rate has been taken in accordance with the observed average GDP growth rates in developed nations.

The CO_2 emissions with respect to GDP have been calculated using the already available sectoral estimates of CO_2 emissions for the period 2000-2005 (Garg et al., 2006; ECS, 2006-07) and corresponding economic values of GDP (in crore rupees; one crore rupees are equal to 10 million rupees) which result in the development of carbon emission intensity factors per unit of GDP (i.e. carbon dioxide emissions per crore rupee) for the years 2000 and 2005. Using this methodology, the carbon emission intensity factor for the economy for the year 2000 was calculated to be 553.3 tons CO_2/crore rupees corresponding to release of 1032 TgCO_2 carbon dioxide emissions related to 1,864,773 crore rupees of GDP for that particular year. On similar lines the carbon emission intensity factor for the year 2005 was calculated to be 471.9 tons CO_2/crore rupees corresponding to a release of 1229 TgCO_2 emissions related to 2,604,532 crore rupees of GDP for the year 2005.

The difference between the carbon emission intensity factors of GDP for the years 2000 and 2005 shows a CO_2 emission reduction value of 81.4 tons CO_2/crore rupees which is an indication of higher energy efficiency achieved by the Indian economy in recent years due to implementations of several technological and management measures in India.

Assuming this trend of CO_2 efficiency of Indian economy to continue till the year 2020, the CO_2 emissions for the years 2010, 2015 and 2020 have been calculated by subtracting the CO_2 emission reduction value (81.4 tons CO_2/crore rupees) from the carbon emission intensity factor respectively of the years 2005, 2010 and 2015. Thus, the carbon emission intensity factors for the years 2010, 2015 and 2020 have been estimated to be 390.4 tons CO_2/crore rupees, 309.0 tonsCO_2/crore rupees and 227.5 tons CO_2/crore rupees respectively. After 2020, the carbon emission intensity factor has been kept as constant as the year 2020 value till the year 2050. Thereafter till 2100 the emissions are kept as constant at the year 2050 value.

Further, by multiplying the carbon intensity factor of the GDP and the GDP values (in crore rupees), the CO_2 emissions have been calculated. CO_2 emissions for the years 2010, 2020, 2050 have thus been calculated to be 0.4 PgC, 0.6 PgC and 1.9 PgC respectively. Further for the period 2050-2100, the CO_2 emissions have been kept constant till the year 2100 (Figure 3.1, Table 1).

CH_4 and N_2O emissions were used in this approach as similar to that of BAU and BCS approaches assuming that significance of sources responsible for emissions of CH_4 and N_2O are similar in these cases (Figures 3.2, 3.3; Tables 2, 3).

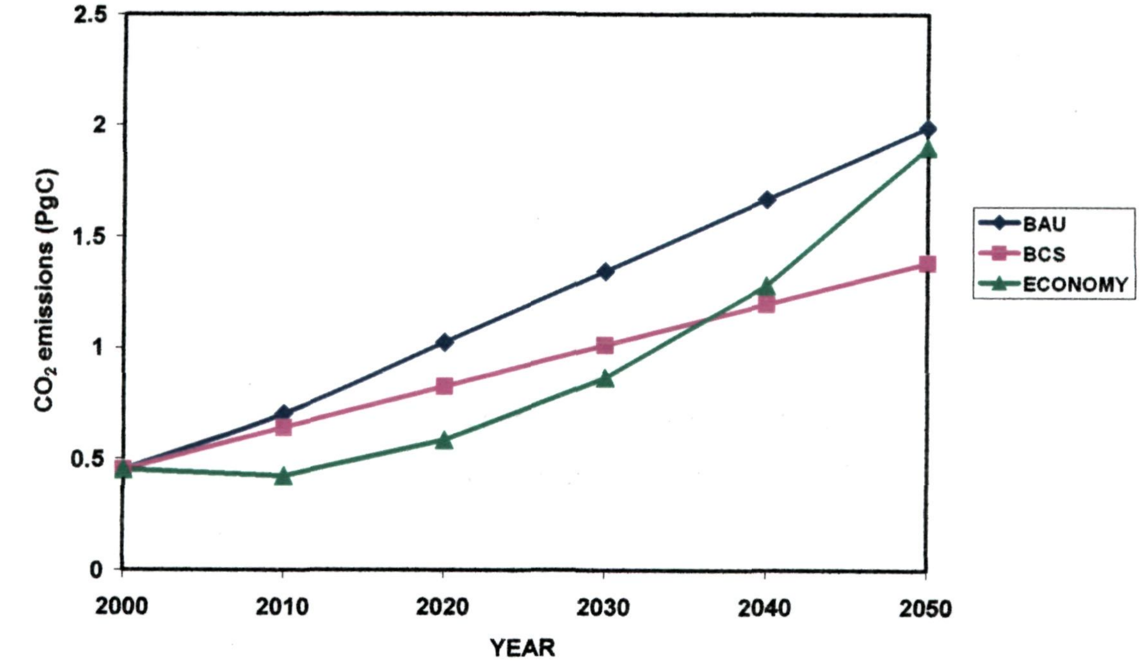

Figure 3.1 Indian carbon dioxide emissions

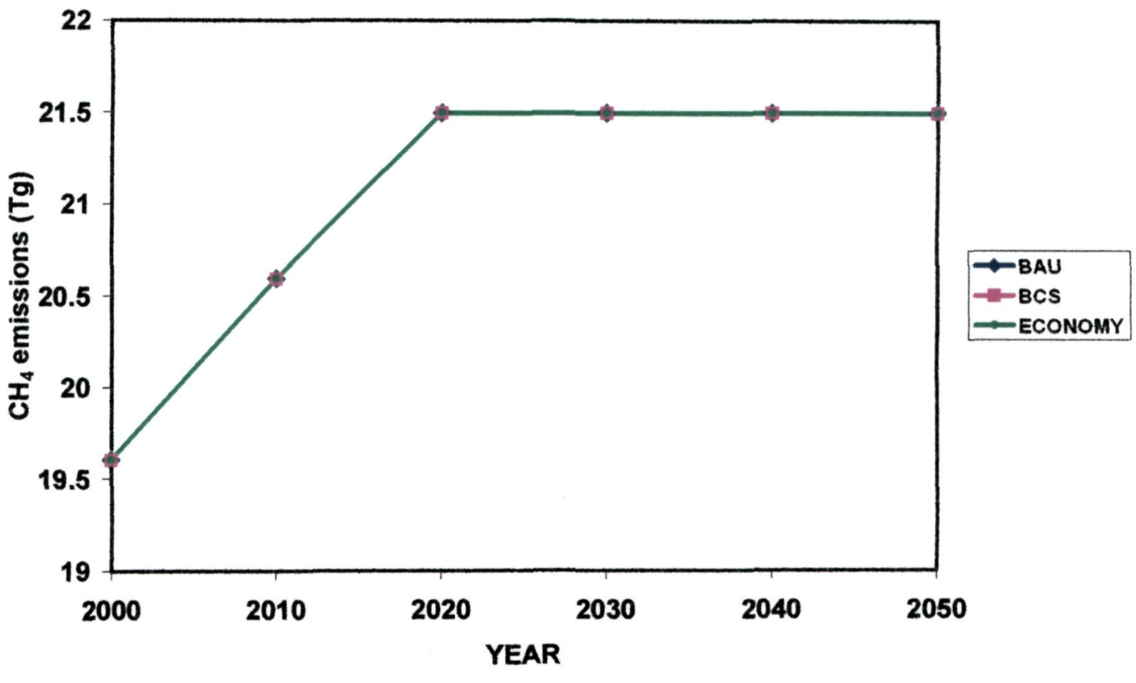

Figure 3.2 Indian methane emissions

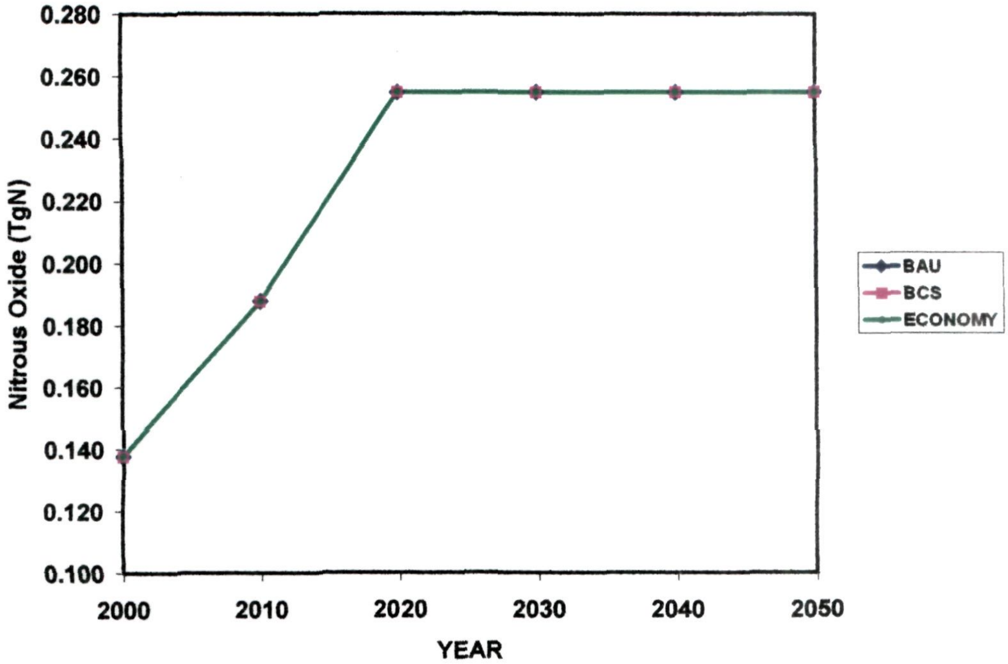

Figure 3.3 Indian nitrous oxide emissions

For modeling exercise using ECONOMY approach, the modified scenario is generated by incorporating the generated India specific values in the default global emission inventories from the year 2000 onwards. The inventories for the year 1990 period have been considered as the initial inputs to the model.

The values for Indian GHG emission estimates obtained for BAU, BCS and ECONOMY approaches (Tables 3.1,3.2,3.3) are then substituted in the global GHG emission values in the default MAGICC scenarios (P50, A1B-AIM, A2 AIM, B1 AIM and B2 AIM) to get modified scenarios.

Further, the modified global GHG emission values were substituted in the default MAGICC simulations. The substitution in the default scenarios was done on the basis of global and Indian per capita emissions. First, the global per capita emissions of CO_2, CH_4 and N_2O were calculated from the default global inventory. Further the Indian contribution to the global CO_2, CH_4 and N_2O emissions as present in the default global MAGICC scenarios, were apportioned by using the global per capita emissions of CO_2, CH_4 and N_2O. These apportioned Indian emission values were then substituted with the modified Indian CO_2, CH_4 and N_2O emissions values generated for the BAU, BCS and ECONOMY approaches. This substitution then leads to the development of corresponding BAU, BCS and ECONOMY global emission scenarios, which have further been substituted in the MAGICC emission library to act as inputs. MAGICC then undergoes the budget balancing for the three GHGs (viz. CO_2, CH_4 and N_2O) and produced the global GHG concentrations outputs for future time periods upto 2100. Furthermore, outputs for RF and ΔT are also produced. These MAGICC results in conjunction with the results of the seventeen AOGCMs present in SCENGEN provide outputs in the form of coded maps for change in surface temperature (ΔT), percent change in precipitation, actual temperature, actual precipitation (both annually and seasonally) for four seasons viz. DJF (December, January & February), MAM (March, April & May), *JJA (June, July & August) and SON (September, October & November). The obtained* output results are discussed in detail in the next chapter 4 under 'Results and Discussion'.

Chapter 4

Results and Discussion

This chapter encompasses the results obtained for the fifteen global emission scenarios which have been developed for this study, as discussed in the previous chapter. The discussion has been divided into two main sections namely; section 4A wherein MAGICC outputs have been discussed and section 4B wherein SCENGEN outputs have been discussed. Section 4A has been further divided into sub-sections namely sub-section A covering projections of global CO_2 emissions, global CH_4 emissions, global N_2O emissions and sub-section B covering the inputs of GHG emissions on various parameters like global CO_2 concentration, global CH_4 concentration, global N_2O concentration, global radiative forcings of CO_2, CH_4 and N_2O, global mean temperature change incorporating aerosol effects and the global mean sea level change and global mean temperature change with aerosol effects kept constant at the 1990 value, as obtained by MAGICC code run. The results have obtained on an annual basis till the year 2100.

Section 4B presents the output results for SCENGEN run. The output results of MAGICC act as input to SCENGEN code. The outputs obtained from SCENGEN run have been discussed under various sub-sections. The sub-sections depict the outputs obtained for the change in global mean temperature and change in global mean precipitation. These results are followed by the outputs for actual values (i.e. sum of the values of change observed in the parameter and the value of the parameter obtained by the model) of global temperature and precipitation for P50 band of scenarios. The SCENGEN outputs of annual change in mean temperature and annual change in precipitation, annual actual mean temperature and annual actual mean precipitation are discussed for all the scenarios. The outputs depicting seasonal changes in temperature and precipitation for P50 band of scenarios and outputs of actual seasonal temperature and actual seasonal precipitation are discussed in another sub-section. Thus, in this section 4B, annual global outputs for changes in temperature and precipitation are presented followed by outputs for actual annual temperature and precipitation obtained from the models. Further, seasonal outputs for change in temperature and precipitation as well as for actual temperature and actual precipitation for P50 band of scenarios have also been discussed. The seasonal outputs represent four seasons, namely DJF (December, January, February), MAM (March, April, May), JJA (June, July, August) and SON (September, October, November).

The scenarios, which have been considered in this study for comparison, are P50 scenario, which is the median of all SRES scenarios and A1B, A2, B1 and B2 SRES scenarios for AIM model. In addition, three modified scenarios incorporating India specific emission inventories namely BAU, BCS and ECONOMY scenarios have also been used to identify the impacts of India specific GHG emission values on model output parameters. The results for various parameters obtained as model outputs are as discussed below.

Section 4A

MAGICC Model Outputs

4A. MAGICC Model Outputs

The MAGICC emission scenario outputs, using the default as well as modified global emission scenarios incorporating India specific inventories are discussed hereunder in the two sub-sections A and B. The sub-section A provides the results of the MAGICC outputs for future global emissions of CO_2, CH_4 and N_2O while sub-section B provides the impacts of these emission scenarios on other climatic parameters like GHG concentrations, radiative forcing, temperature and sea-level obtained from MAGICC run.

(A) Global emissions of CO_2, CH_4 and N_2O

The global CO_2 (both from fossil fuel combustion and deforestation), CH_4 and N_2O emissions for the period 2000-2100 as obtained from MAGICC run are discussed below:

4A.1 Global CO_2 emission from fossil fuel combustion

The CO_2 emission scenarios from fossil fuel combustion (Figure 4.1) show that until 2050, there is, by and large a general increase in CO_2 emissions. However, beyond 2050, the magnitude of increase seem to be different in different SRES scenarios e.g. scenarios A2, BAU A2, BCS A2 and ECONOMY A2 depict an exponentially increasing trajectory until 2100 while the B1 scenario family like B1, BAU B1, BCS B1 and ECONOMY B1 show a peak at 2050 and then a decrease in CO_2 emissions from the year 2050 to 2100. Moreover, scenarios A1B, BAU A1B, BCS A1B, ECONOMY A1B, B2, BAU B2, BCS B2 and ECONOMY B2 also depict a slight decrease in CO_2 emissions for this time period. Scenarios P50, BAU P50, BCS P50 and ECONOMY P50 indicate a more or less constant growth in emissions.

For the year 2050, global CO_2 emissions from fossil fuel combustion range from 11.7 to 16.6 PgC, respectively for modified scenario BCS B1 and scenario A2. For the year 2050, global CO_2 emissions from fossil fuel for P50 band of scenarios ranges from 14.1 to 15.4 PgC; for A1B band of scenarios it ranges from 14.5 to 16.0 PgC; for A2 band of scenarios, it ranges from 15.0 PgC to 16.6 PgC; for B1 band of scenarios, it ranges from 11.7 to 12.6 PgC and for B2 band of scenarios, it ranges from 14.2 to 15.0 PgC.

For the year 2100, global CO_2 emissions from fossil fuel range from 6.4 to 33.4 PgC respectively for B1 and A2 scenarios. For the year 2100, global CO_2 emissions from fossil fuel for P50 band of scenarios ranges from 15.8 to 17.6 PgC, for A1B band of scenarios it ranges from 12.2 to 13.1 PgC, for A2 band of scenarios it ranges from 28.9 to 33.4 PgC, for B1 band of scenarios it ranges from 6.4 to 7.3 PgC and for B2 band of scenarios it ranges from 12.8 to 13.9 PgC (Table 4).

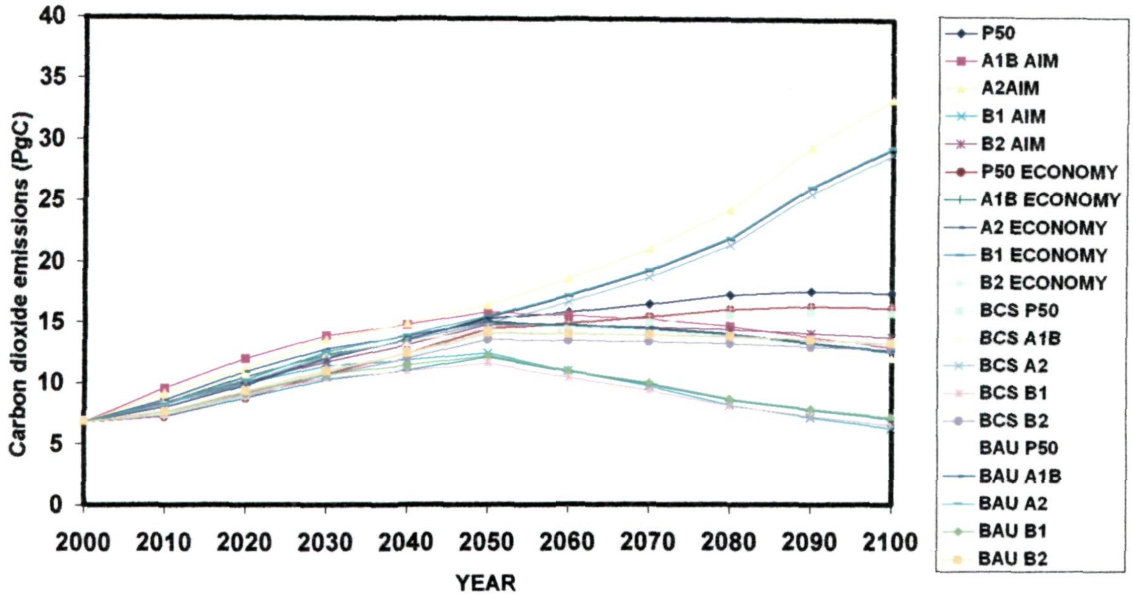

Figure 4.1 Global carbon dioxide emissions from fossil fuel combustion

Global CO_2 emissions from fossil fuel combustion for the modified BAU scenarios range from 7.3 to 29.5 PgC, for modified BCS scenarios range from 6.7 to 28.9 PgC and for modified ECONOMY scenarios range from 7.2 to 29.4 PgC.

4A.2 Global CO_2 emission from deforestation

The CO_2 emission scenarios from deforestation (Figure 4.2) show that until 2050, there is, by and large, a general decrease in CO_2 emissions except in A2 scenario where it shows an increasing trend. Beyond 2050 also, A2 scenario shows an increasing trend contrary to the rest. The A1B scenario also shows an increase but the magnitude of increase is very less as compared to A2 scenario. Increase in A2 scenario is attributed to the fact that the theme of A2 scenarios is self reliance and preservation of local identities. Thus, in this scenario, the global population increases at an alarming rate. This leads to increase in deforestation for accommodating and meeting the additional demands of increasing population (Table 5).

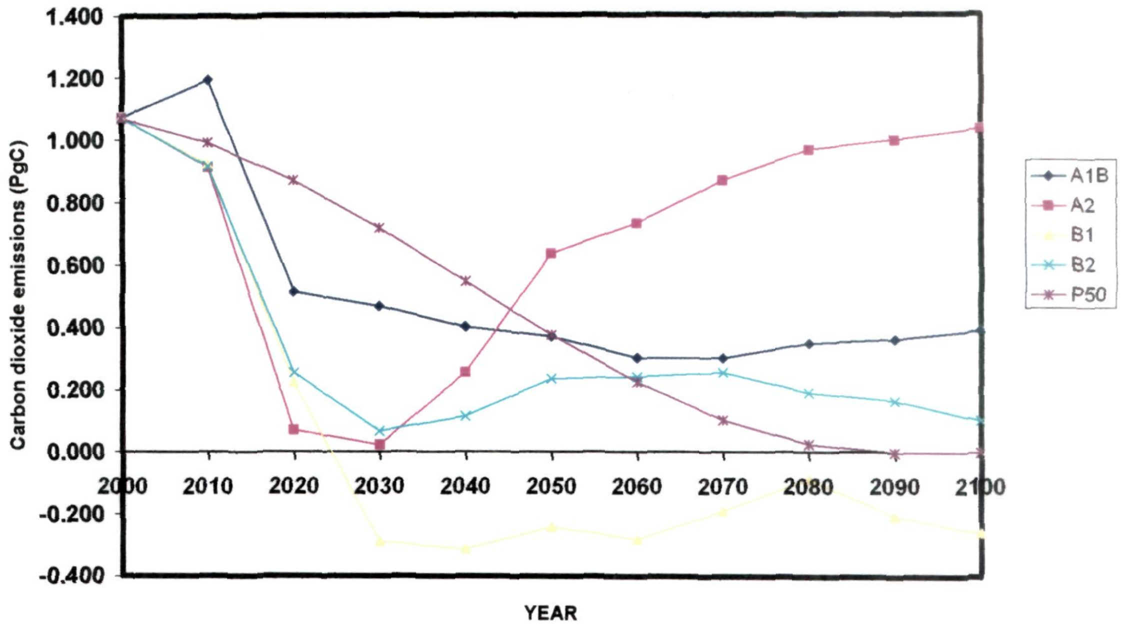

Figure 4.2 Global carbon dioxide emissions from deforestation

4A.3 Global CH_4 emission

The CH_4 emission scenarios (Figure 4c) show that until 2050, there is, by and large, a general increase in CH_4 emissions except in A1B group of scenarios. However, beyond 2050, a general decrease in emissions is observed under different SRES scenarios albeit with different magnitudes of decrease e.g. scenarios A1B, BAU A1B, BCS A1B, ECONOMY A1B, B1, BAU B1, BCS B1 and ECONOMY B1 depict a parabolic decrease from the year 2050 to 2100. Scenarios P50, BAU P50, BCS P50, ECONOMY P50 and B2, BAU B2, BCS B2 and ECONOMY B2 also depict a slight decrease in CH_4 emissions. A variation from the general decrease is depicted by the scenarios A2, BAU A2, BCS A2 and ECONOMY A2 which show increasing trajectory until 2100.

For the year 2050, global CH_4 emissions range from 376.6 to 525.0 Tg respectively for modified BAU A2, BCS A2, ECONOMY A2 and P50 scenarios. For the year 2050, global CH_4 emissions for P50 band of scenarios ranges from 451.7 to 525.0

Tg, for A1B band of scenarios it ranges from 391.9 to 452.3 Tg, for A2 band of scenarios it ranges from 376.6 to 433.6 Tg, for B1 band of scenarios it ranges from 389.3 to 449.1 Tg and for B2 band of scenarios it ranges from 402.1 to 481.9 Tg.

For the year 2100, global CH_4 emission estimates range from 224.0 to 549.1 Tg respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario A2. For the year 2100, global CH_4 emissions for P50 band of scenarios ranges from 441.5 Tg to 512.7 Tg, for A1B band of scenarios it ranges from 257.8 to 289.2 Tg, for A2 band of scenarios it ranges from 471.5 to 549.1 Tg, for B1 band of scenarios it ranges from 224.1 to 248.1 Tg and for B2 band of scenarios it ranges from 402.1 to 464.7 Tg (Table 6).

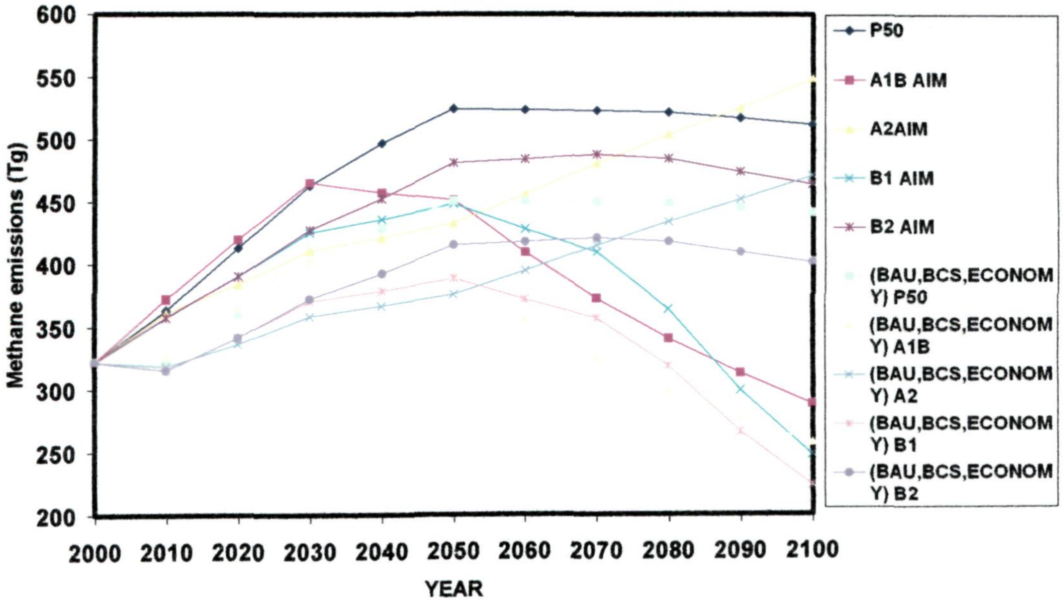

Figure 4.3 Global methane emissions

Global CH_4 emissions for the modified BAU, BCS and ECONOMY scenarios range from 224.1 to 471.5 Tg. A2 band of scenarios show an increasing trend after 2050, whereas the B1 and A1B band of scenarios indicate a decrease in methane emissions for 2050-2100 period. Somewhat constant CH_4 emissions are indicated by P50 and B2 band of scenarios.

4A.4 Global N_2O emission

The N_2O emission scenarios (Figure 4.4) show that until 2050, there is by and large a general increase in N_2O emissions except under the scenarios B1, BAU B1, BCS B1 and ECONOMY B1. However beyond 2050, the trends of different scenarios are different e.g. scenarios A2, BAU A2, BCS A2, ECONOMY A2 depict a linearly increasing trajectory until 2100, while, scenario P50 indicate maximum increase with scenarios BAU P50, BCS P50, ECONOMY P50 follow the trends observed under the A2 scenario. Scenarios B2, BAU B2, BCS B2 and ECONOMY B2 depict slightly increasing emission trajectory from the year 2050 to 2100 while scenarios A1B, BAU A1B, BCS A1B and ECONOMY A1B show a decrease in N_2O emissions from the year 2050 to 2100.

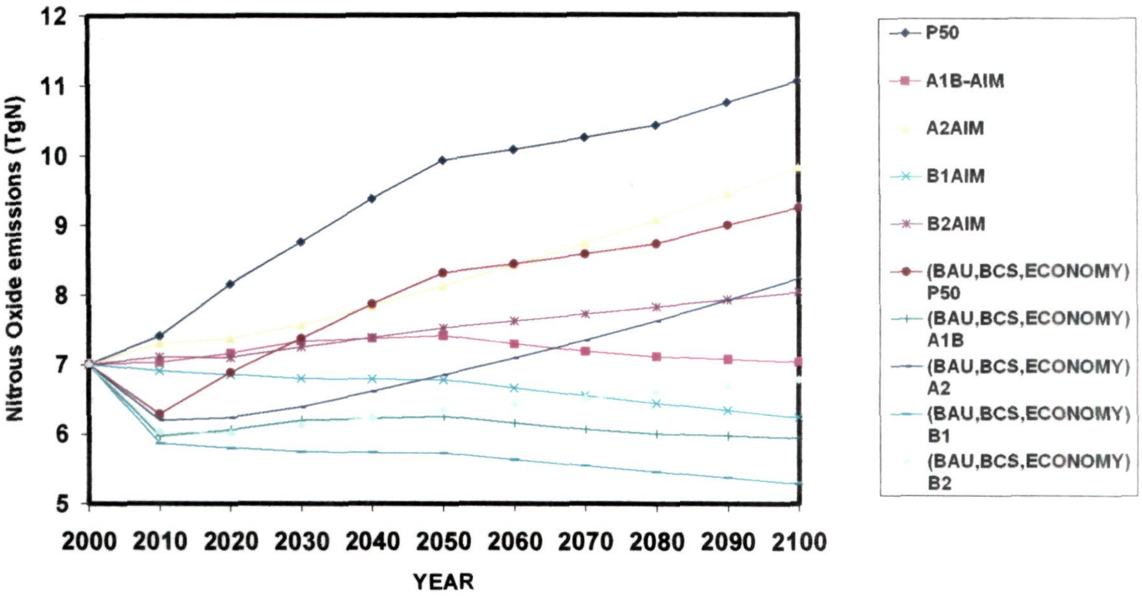

Figure 4.4 Global nitrous oxide emissions

For the year 2050, global N_2O emission estimates range from 5.7 to 9.9 TgN respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2050, global N_2O emissions for P50 band of scenarios range from 8.3 to 9.9 TgN, for A1B band of scenarios it range from 6.3 to 7.4 TgN, for A2 band of scenarios it range from 6.8 to 8.1 TgN, for B1 band of scenarios it range from 5.7 to 6.8 TgN and for B2 band of scenarios it range from 6.4 to 7.5 TgN.

For the year 2100, global N_2O emissions show a range from 5.3 to 11.1 TgN respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2100, global N_2O emissions for P50 band of scenarios range from 9.3 to 11.1 TgN, for A1B band of scenarios it ranges from 5.9 to 7.0 TgN, for A2 band of scenarios it ranges from 8.2 to 9.8 TgN, for B1 band of scenarios it ranges from 5.3 to 6.2 TgN and for B2 band of scenarios it ranges from 6.8 to 8.0 TgN (Table 7). Global N_2O emissions for the modified BAU, BCS and ECONOMY scenarios range from 6.8 to 9.8 TgN.

(B) Effect of global emissions of CO_2, CH_4 and N_2O on GHG concentration and other parameters

The global emissions of CO_2, CH_4 and N_2O change the global GHG concentrations and affects the other parameters like resulting radiative forcing, mean temperature, sea-level rise etc, which are discussed as below:

4A.5 Global CO_2 concentration

The CO_2 concentration scenarios (Figure 4.5) show that until 2050, there is by and large a general increase in CO_2 concentrations. However beyond 2050, the magnitudes of increase are different in different SRES scenarios e.g. scenarios A2, BAU A2, BCS A2 and ECONOMY A2 depict an exponentially increasing trajectory until 2100, however scenarios B2, BAU B2, BCS B2, ECONOMY B2, P50, BAU P50, BCS P50, ECONOMY P50, A1B, BAU A1B, BCS A1B and ECONOMY A1B depict a somewhat linearly increasing trajectory until 2100 while the scenarios B1, BAU B1, BCS B1 and ECONOMY B1 show CO_2 concentration becoming constant from the year 2050 till 2100.

For the year 2050, global CO_2 concentrations range from 479.0 to 535.8 ppmv respectively for scenarios ECONOMY B1 and A1B. For the year 2050, global CO_2 concentration for P50 band of scenarios range from 499.8 to 516.1 ppmv, for A1B band of scenarios it ranges from 515.4 to 535.8 ppmv, for A2 band of scenarios it ranges from 508.4 to 528.1 ppmv, for B1 band of scenarios it ranges from 479.0 to 492.7 ppmv and for B2 band of scenarios it ranges from 492.3 to 508.0 ppmv.

For the year 2100, global CO_2 concentration ranges from 553.4 to 880.9 ppmv respectively for modified scenario BCS B1 and scenario A2. For the year 2100, global CO_2 concentration for P50 band of scenarios ranges from 686.1 to 727.8 ppmv, for A1B band of scenarios it ranges from 670.9 to 708.6 ppmv, for A2 band of scenarios it ranges from 813.5 to 880.9 ppmv, for B1 band of scenarios it ranges from 553.4 to 566.7 ppmv and for B2 band of scenarios it ranges from 647.3 to 680.2 ppmv (Table 8).

Global CO_2 concentrations for the modified BAU scenarios range from 566.7 to 828.7 ppmv, for modified BCS scenarios this range extends from 553.4 to 813.5 ppmv and for modified ECONOMY scenarios it ranges from 560.9 to 822.0 ppmv.

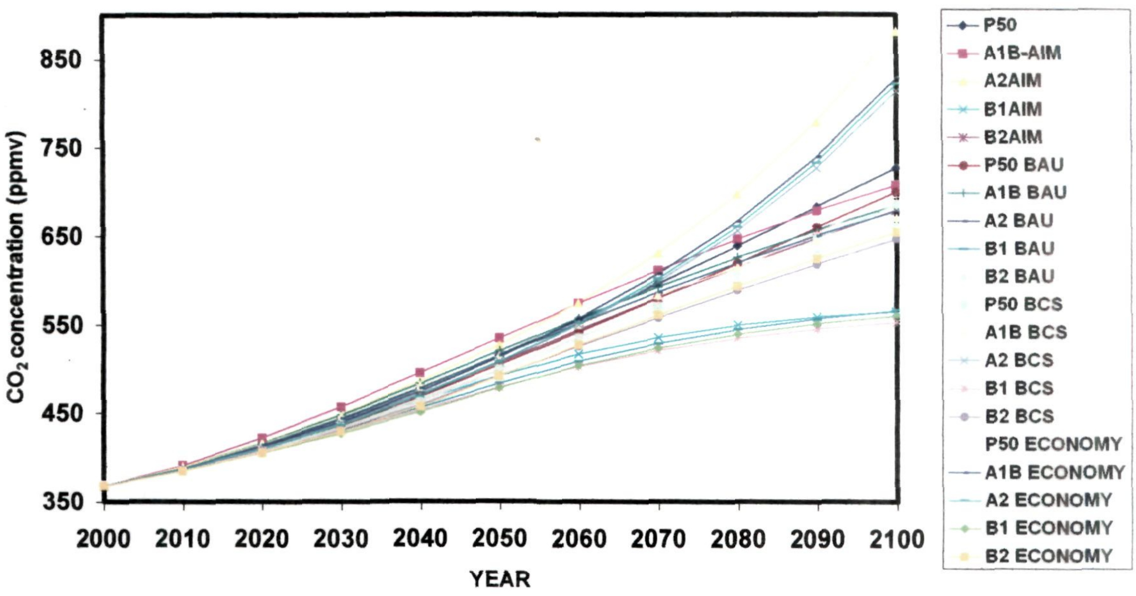

Figure 4.5 Global carbon dioxide concentration

4A.6 Global CH_4 concentration

The scenarios for CH_4 concentration (Figure 4.6) show that until 2050, there is by and large a general increase in CH_4 concentration. However beyond 2050, the magnitudes of increase seem to be different in different SRES scenarios e.g. scenarios A2, BAU A2, BCS A2 and ECONOMY A2 depict an slightly exponentially increasing trajectory until 2100, however scenarios, P50, BAU P50, BCS P50, ECONOMY P50, B2, BAU B2, BCS B2 and ECONOMY B2 depict a somewhat polynomially increasing trajectory until 2100 while the scenarios A1B, BAU A1B, BCS A1B, ECONOMY A1B, B1, BAU B1, BCS B1 and ECONOMY B1 show CH_4 concentration decreasing parabolically from the year 2050 to 2100.

For the year 2050, global CH_4 concentration range from 2123.9 to 2461.8 ppbv respectively for modified scenarios BAU A2, BCS A2, ECONOMY A2 and scenario P50. For the year 2050, global CH_4 concentration for P50 band of scenarios ranges from 2322.1 to 2461.8 ppbv, for A1B band of scenarios it ranges from 2285.5 to 2399.7 ppbv, for A2 band of scenarios it ranges from 2123.9 to 2210.2 ppbv, for B1 band of scenarios it ranges from 2220.2 to 2318.7 ppbv and for B2 band of scenarios it ranges from 2286.6 to 2399.1 ppbv.

For the year 2100, global CH_4 concentration ranges from 1902.5 to 2715.8 ppbv respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2100, global CH_4 concentration for P50 band of scenarios ranges from 2538.3 to 2715.8 ppbv, for A1B band of scenarios it ranges from 1953.0 to 1970.1 ppbv, for A2 band of scenarios it ranges from 2431.8 to 2603.5 ppbv, for B1 band of scenarios it ranges from 1902.5 to 1911.2 ppbv and for B2 band of scenarios it ranges from 2493.2 to 2639.3 ppbv to (Table 9).

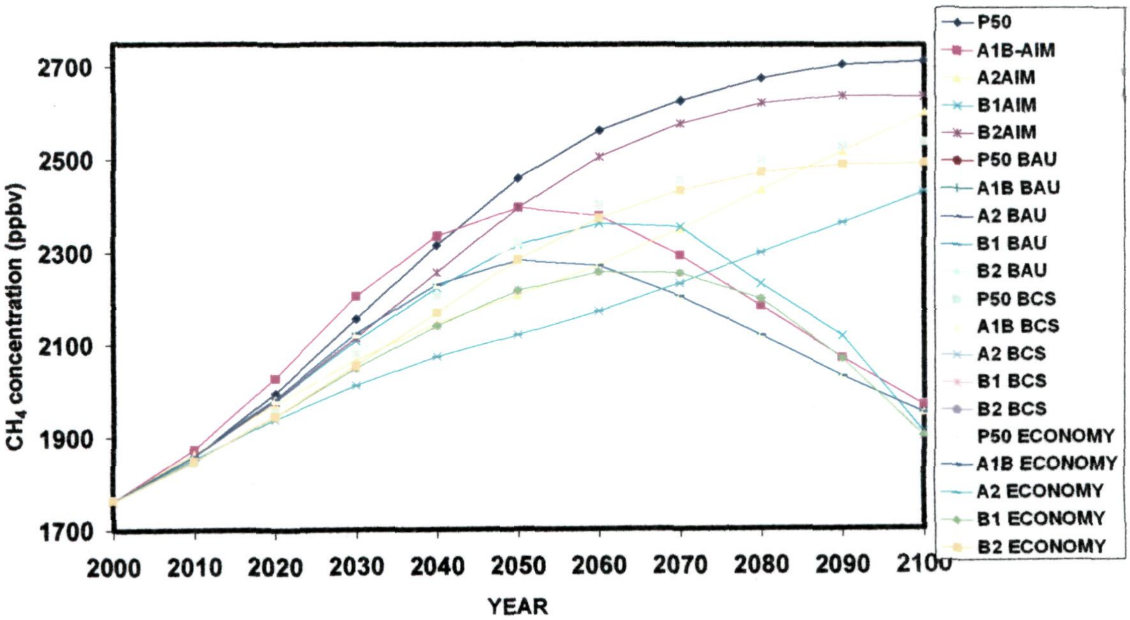

Figure 4.6 Global methane concentration

Global CH_4 concentrations for the modified BAU, BCS and ECONOMY scenarios range from 1902.5 to 2538.3 ppbv.

4A.7 Global N_2O concentration

The scenarios for N_2O concentration (Figure 4.7) show that until 2050, there is by and large a general increase in N_2O concentration and this trend continues till 2100.

For the year 2050, global N_2O concentration range from 347.9 to 362.7 ppbv respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2050, global N_2O concentration for P50 band of scenarios ranges from 359.9 to 362.7 ppbv, for A1B band of scenarios it ranges from 350.7 to 351.5 ppbv, for A2 band of scenarios it ranges from 353.0 to 354.3 ppbv, for B1 band of scenarios it ranges from 347.9 to 348.0 ppbv and for B2 band of scenarios it ranges from 350.7 to 351.5 ppbv.

For the year 2100, global N_2O concentration ranges from 365.1 to 408.4 ppbv respectively for scenarios B1 and P50. For the year 2100, global N_2O concentration for P50 band of scenarios ranges from 400.9 to 408.4 ppbv, for A1B band of scenarios it ranges from 371.8 to 373.1 ppbv, for A2 band of scenarios it ranges from 386.3 to 390.7 ppbv, for B1 band of scenarios it ranges from 365.1 to 365.2 ppbv to and for B2 band of scenarios it ranges from 376.3 and 378.6 ppbv (Table 10).

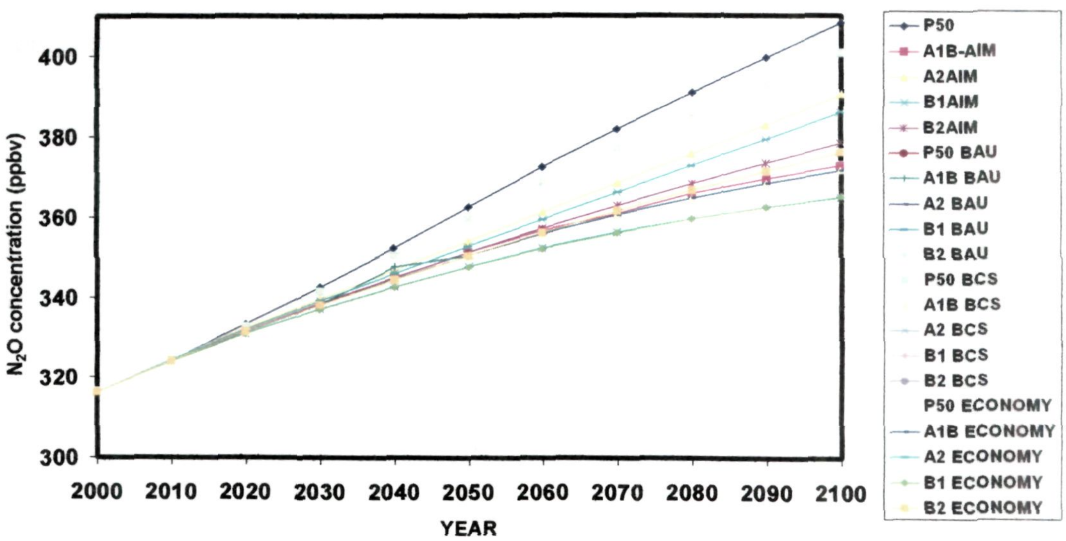

Figure 4.7 Global nitrous oxide concentration

Global N_2O concentrations for the modified BAU, BCS and ECONOMY scenarios range from 365.2 to 400.9 ppbv.

4A.8 Global radiative forcing

4A.8.1 CO_2 radiative forcing

The scenarios for CO_2 radiative forcing (Figure 4.8) show that until 2050, there is by and large a general increase in CO_2 radiative forcing and this trend continues till 2100. Scenarios A2, BAU A2, BCS A2 and ECONOMY A2 indicate the greatest increase. Scenarios B1, BAU B1, BCS B1 and ECONOMY B1 tend to become constant around 2100 and all the rest of scenarios lie within this range.

For the year 2050, global CO_2 radiative forcing ranges from 1.6 to 2.2 Wm^{-2} respectively for modified scenario ECONOMY B1 and scenario A1B. For the year 2050, global CO_2 radiative forcing for P50 band of scenarios ranges from 1.8 to 2.0 Wm^{-2}, for A1B band of scenarios it ranges from 2.0 to 2.2 Wm^{-2}, for A2 band of scenarios it ranges from 1.9 Wm^{-2} to 2.1 Wm^{-2}, for B1 band of scenarios it ranges from 1.6 to 1.8 Wm^{-2} and for B2 band of scenarios it ranges from 1.8 to 1.9 Wm^{-2}.

For the year 2100, global CO_2 radiative forcing ranges from 2.4 to 4.9 Wm^{-2} respectively for modified scenario BCS B1 and scenario A2. For the year 2100, global CO_2 radiative forcing for P50 band of scenarios ranges from 3.5 to 3.9 Wm^{-2}, for A1B band of scenarios it ranges from 3.4 to 3.7 Wm^{-2}, for A2 band of scenarios it ranges from 4.5 to 4.9 Wm^{-2}, for B1 band of scenarios it ranges from 2.4 to 2.5 Wm^{-2} and for B2 band of scenarios it ranges from 3.2 to 3.5 Wm^{-2} (Table 11).

Global CO_2 radiative forcing for the modified BAU scenarios ranges from 2.5 to 4.6 Wm^{-2}, for modified BCS scenarios it ranges from 2.4 to 4.5 Wm^{-2} and for modified ECONOMY scenarios global CO_2 radiative forcing range from 2.5 to 4.5 Wm^{-2}.

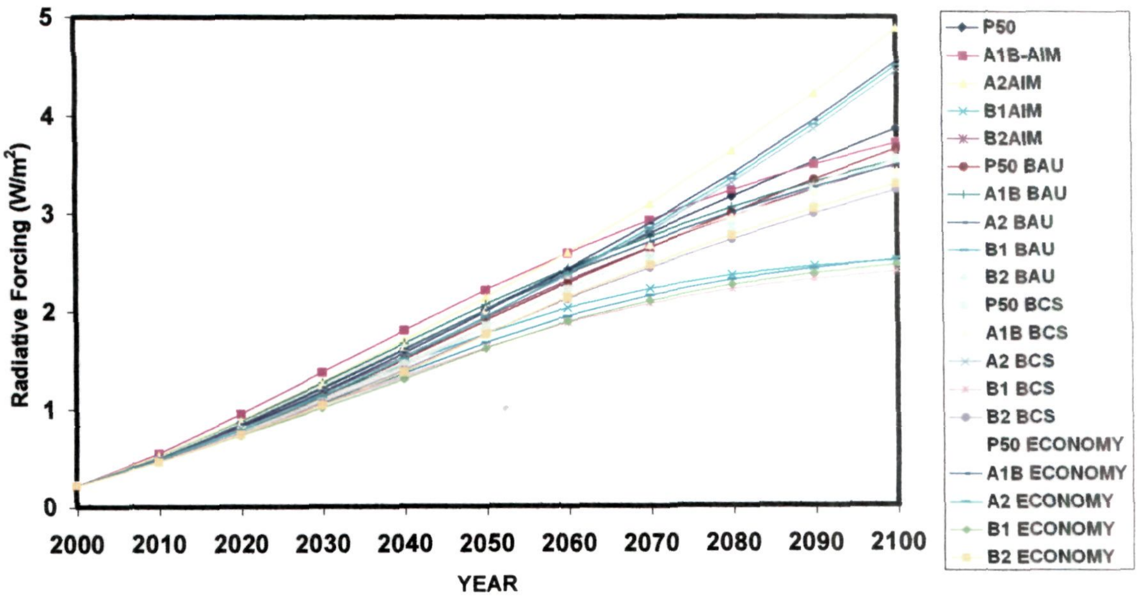

Figure 4.8 Carbon dioxide radiative forcing

4A.8.2 CH_4 radiative forcing

The scenarios for CH_4 radiative forcing (Figure 4.9) show that radiative forcing trend is consistent and in line with their respective concentration outputs till 2100.

For the year 2050, global CH_4 radiative forcing ranges from 0.2 to 0.3 Wm^{-2} respectively for modified scenarios BAU A2, BCS A2, ECONOMY A2 and scenario P50. For the year 2050, global CH_4 radiative forcing for P50 band of scenarios ranges from 0.2 to 0.3 Wm^{-2}, for A1B band of scenarios it ranges from 0.2 to 0.3 Wm^{-2}, for A2 band of scenarios it ranges from 0.1 to 0.2 Wm^{-2}, for B1 band of scenarios it ranges from 0.19 to 0.22 Wm^{-2} and for B2 band of scenarios it ranges from 0.2 to 0.3 Wm^{-2}.

For the year 2100, global CH_4 radiative forcing ranges from 0.1 to 0.4 Wm^{-2} respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2100, global CH_4 radiative forcing for P50 band of scenarios ranges from 0.3 to 0.4 Wm^{-2}, for A1B band of scenarios it ranges from 0.09 to 0.10 Wm^{-2}, for A2 band of scenarios it ranges from 0.27 to 0.32 Wm^{-2}, for B1 band of scenarios it ranges from 0.07 to 0.08 Wm^{-2} and for B2 band of scenarios it ranges from 0.28 to 0.33 Wm^{-2} (Table 12).

Global CH_4 radiative forcing for the modified BAU, BCS and ECONOMY scenarios range from 0.1 to 0.3 Wm^{-2}.

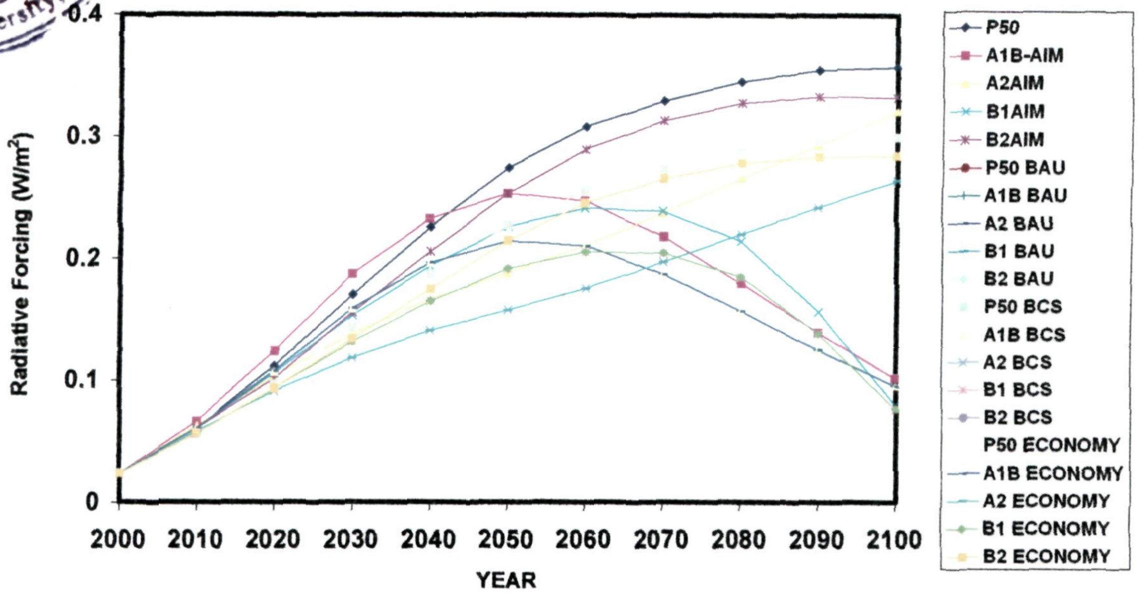

Figure 4.9 Methane radiative forcing

4A.8.3 N_2O radiative forcing

In case of N_2O radiative forcing (Figure 4.10), the pattern is almost identical in all the scenarios because of the N_2O emissions contributing to only a small fraction in the radiative forcing.

For the year 2050, global N_2O radiative forcing ranges from 0.1 to 0.2 Wm^{-2} respectively for modified scenarios BAU B1, BCS B1, ECONOMY B1 and scenario P50. For the year 2050, global N_2O radiative forcing for P50 band of scenarios ranges from 0.16 to 0.17 Wm^{-2}, for A1B and B2 the value of radiative forcing remains somewhat constant at 0.13 Wm^{-2}, for A2 band of scenarios radiative forcing is about 0.14 Wm^{-2} and for B1 band of scenarios it has a value of 0.12 Wm^{-2}.

For the year 2100, global N_2O radiative forcing ranges from 0.2 to 0.3 Wm^{-2} respectively for modified scenario B1 and scenario P50. For the year 2100, global N_2O radiative forcing for P50 band of scenarios ranges from 0.28 to 0.30 Wm^{-2}, for A1B band of scenarios it ranges from 0.19 to 0.20 Wm^{-2}, for A2 band of scenarios it ranges from

0.24 to 0.25 Wm^{-2}, for B1 band of scenarios it ranges from 0.17 to 0.18 Wm^{-2} and for B2 band of scenarios it ranges from 0.20 to 0.21 Wm^{-2} (Table 13).

Global N_2O radiative forcing for the modified BAU, BCS and ECONOMY scenarios range from 0.2 to 0.3 Wm^{-2}.

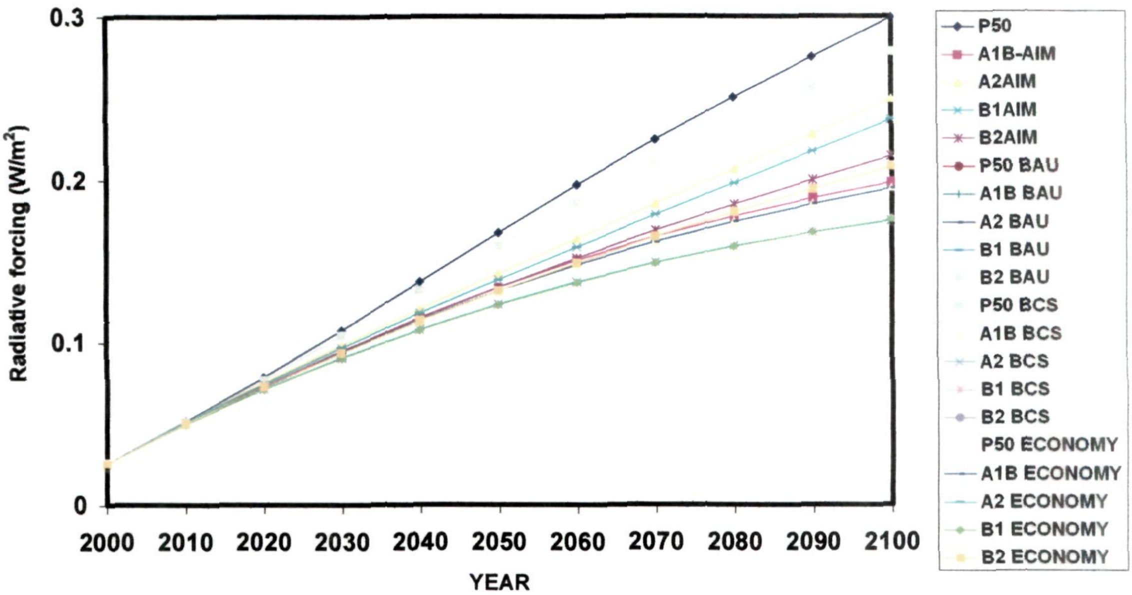

Figure 4.10 Nitrous oxide radiative forcing

4A.9 Global mean temperature change

The scenario for global mean temperature change with respect to 1990 (Figure 4.11) incorporating aerosol effects show an increase in the global mean temperature till 2100 with P50 scenario depicting the greatest increase, while scenarios B1, BAU B1, BCS B1 and ECONOMY B1 show a somewhat constant behavior for 2080-2100 period. Scenarios A2, BAU A2, BCS A2, ECONOMY A2, B2, BAU B2, BCS B2, ECONOMY B2, BAU P50, BCS P50, ECONOMY P50, A1B, BAU A1B, BCS A1B and ECONOMY A1B also show increase until 2100.

For the year 2050, global mean temperature change with respect to 1990 ranges from 0.9 to 1.4°C respectively for modified scenario ECONOMY A2 and scenario P50. For the year 2050, global mean temperature change with respect to 1990 for P50 band of scenarios ranges from 1.3 to 1.4°C, for A1B band of scenarios it ranges from 1.4 to

1.5°C, for A2 band of scenarios it ranges from 0.9 to 1.0°C, for B1 band of scenarios it ranges from 1.3 to 1.4°C and for B2 band of scenarios it ranges from 1.4 to 1.5°C.

For the year 2100, global mean temperature change with respect to 1990 ranges from 2.1 to 3.0°C respectively for modified scenario BCS B1 and scenario P50. For the year 2100, global mean temperature change with respect to 1990 for P50 band of scenarios ranges from 2. 8 to 3.0°C, for A1B band of scenarios it ranges from to 2.6 to 2.8°C, for A2 band of scenarios it ranges from 2.5 to 2.8°C, for B1 band of scenarios it ranges from 2.1 to 2.2°C and for B2 band of scenarios it ranges from 2.5 to 2.7°C (Table 14).

Global mean temperature change for aerosol emissions with respect to year 1990 for the modified BAU scenarios range from 2.2 to 2.8°C, for modified BCS scenarios range from 2.1 to 2.8°C and for modified ECONOMY scenarios range from 2.1 to 2.8°C.

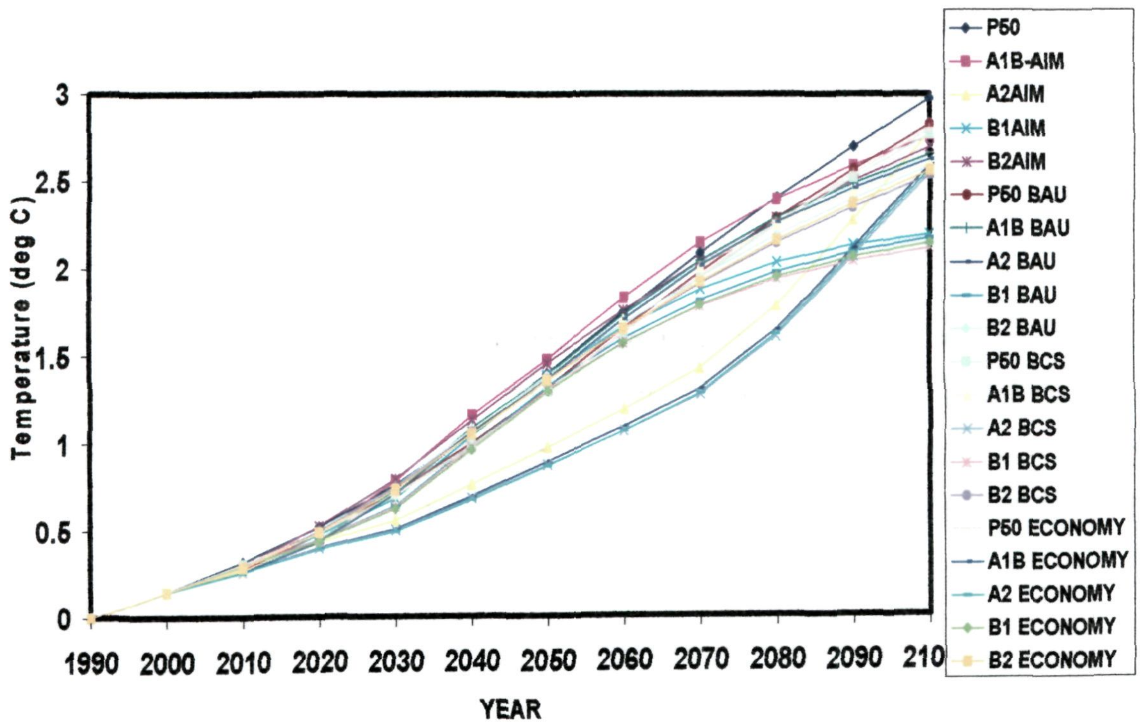

Figure 4.11 Global mean temperature change with respect to 1990 (incorporating aerosol effects)

4A.10 Global mean sea-level change

The scenario for global mean sea level change with respect to 1990 (Figure 4.12) incorporating aerosol effects for the full global region show an increase till 2100 as indicated by all the scenarios A2, BAU A2, BCS A2, ECONOMY A2, B2, BAU B2, BCS B2, ECONOMY B2, P50, BAU P50, BCS P50, ECONOMY P50, A1B, BAU A1B, BCS A1B, ECONOMY A1B B1, BAU B1, BCS B1 and ECONOMY B1.

For the year 2050, global mean change in sea-level ranges from 12.8 to 16.1 cm respectively for modified scenario ECONOMY A2 and scenario A1B. For the year 2050, global mean change in sea-level for P50 band of scenarios ranges from 14.7 to 15.5 cm, for A1B band of scenarios it ranges from 15.2 cm to 16.1 cm, for A2 band of scenarios it ranges from 12.8 to 13.6 cm, for B1 band of scenarios it ranges from 14.4 to 15.2 cm and for B2 band of scenarios it ranges from 15.1 to 15.8 cm.

For the year 2100, global mean change in sea-level ranges from 32.3 to 38.5 cm respectively for modified scenario BCS B1 and scenario P50. For the year 2100, global mean change in sea-level for P50 band of scenarios ranges from 36.5 to 38.5 cm, for A1B band of scenarios it ranges from 36.1 to 37.9 cm, for A2 band of scenarios it ranges from 32.5 to 34.7 cm, for B1 band of scenarios it ranges from 32.3 to 33.4 cm and for B2 band of scenarios it ranges from 35.4 to 37.2 cm (Table 15).

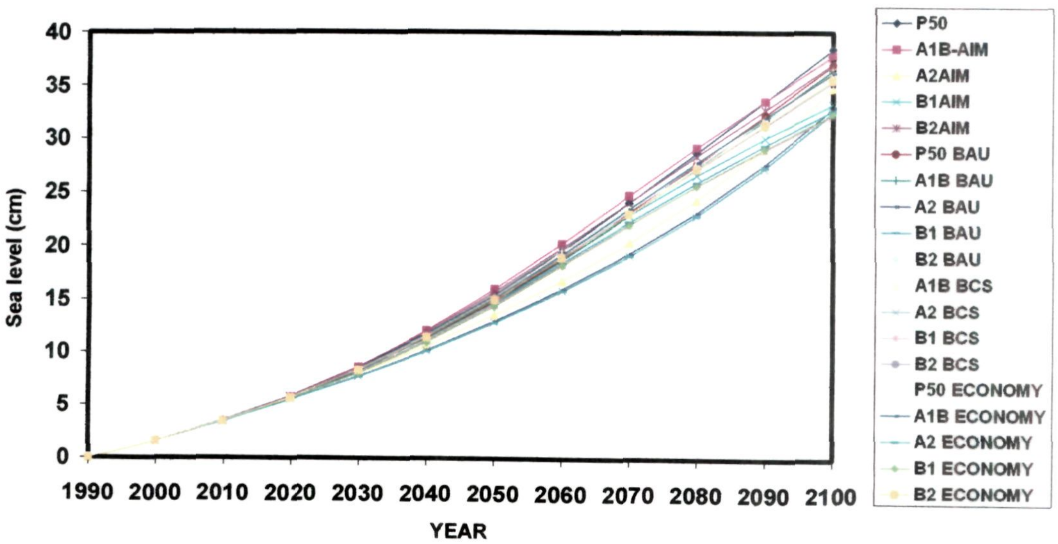

Figure 4.12 Global mean sea level change with respect to 1990 (incorporating aerosols effects)

Global mean sea-level change under the impacts of aerosol emissions with respect to year 1990 for the modified BAU scenarios ranges from 32.8 to 37.0 cm, for modified BCS scenarios ranges from 32.3 to 36.5 cm and for modified ECONOMY scenarios ranges from 32.4 to 36.7 cm.

4A.11 Global mean change in temperature (without aerosols effects)

The scenarios for global mean change in temperature with respect to 1990 (Figure 4.13), in which aerosol effects are kept constant after the 1990 period, show an increase till 2100 as indicated by all the scenarios A2, BAU A2, BCS A2, ECONOMY A2, B2, BAU B2, BCS B2, ECONOMY B2, P50, BAU P50, BCS P50, ECONOMY P50, A1B, BAU A1B, BCS A1B, ECONOMY A1B B1, BAU B1, BCS B1 and ECONOMY B1. It is observed that the increase in temperature is greater in these cases compared to cases where aerosol effects are included.

For the year 2050, global mean temperature change with respect to 1990 ranges from 1.2 to 1.5°C respectively for modified scenario ECONOMY B1 and scenario A1B. For the year 2050, global mean temperature change with respect to 1990 for P50 band of scenarios ranges from 1.3 to 1.4°C, for A1B band of scenarios it ranges from 1.4 to 1.5°C, for A2 band of scenarios it ranges from 1.3 to 1.4°C, for B1 band of scenarios it ranges from 1.2 to 1.3°C and for B2 band of scenarios it ranges from 1.2 to 1.3°C.

For the year 2100, global mean temperature change with respect to 1990 ranges from 1.8 to 3.0°C respectively for modified scenario ECONOMY B1 and scenarios A2. For the year 2100, global mean temperature change with respect to 1990 for P50 band of scenarios ranges from 2.6 to 2.8°C, for A1B band of scenarios it ranges from 2.3 to 2.4°C, for A2 band of scenarios it ranges from 2.8 to 3.0°C, for B1 band of scenarios it ranges from 1.7 to 1.8°C and for B2 band of scenarios it ranges from 2.2 to 2.4°C (Table 16).

Global mean temperature change for aerosol emissions kept constant for post 2000 period for the modified BAU scenarios range from 1.7 to 2.9°C, for modified BCS scenarios range from 1.7 to 2.8°C and for modified ECONOMY scenarios range from 1.8 to 3.0°C.

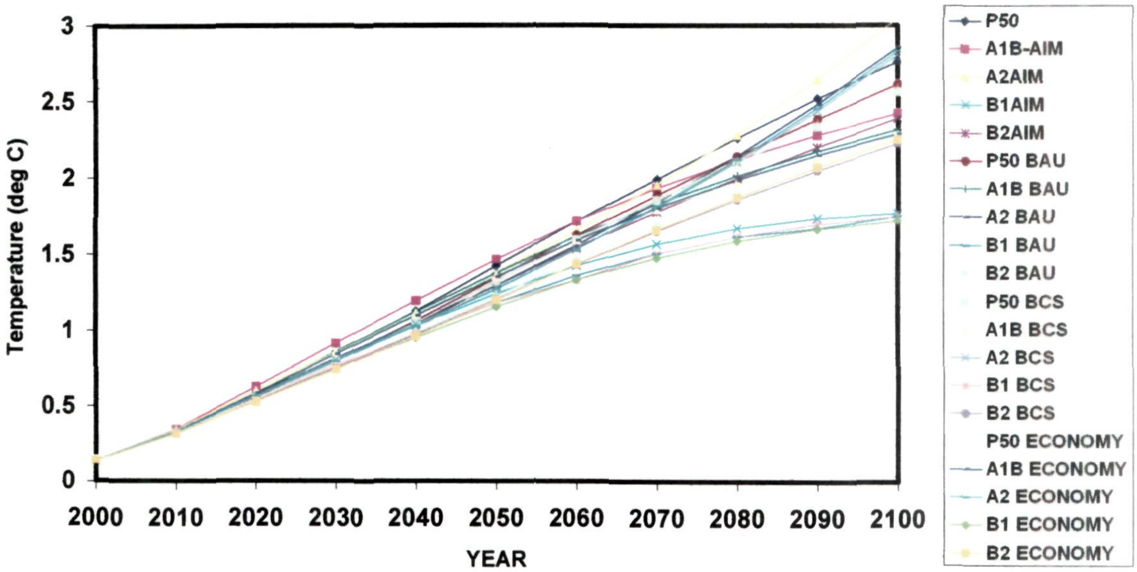

Figure 4.13 Global mean temperature change (without aerosol effects)

Section 4B

SCENGEN Model Outputs

4B. SCENGEN Model Outputs

The MAGICC outputs of GHG concentrations, radiative forcing and global mean temperature, have been used as inputs to SCENGEN model. The SCENGEN results have been obtained for annual change in mean temperature and annual per cent change in precipitation for all the modified scenarios and the default SRES scenarios. The results for global mean surface air temperature and change in annual precipitation obtained are the average of results of all the seventeen models viz., BMRC98, CSI296, GFDL90, IAP_97, WM_95, CCC199, CSM_98, GISS95, LMD_98, CCSR96, ECH395, HAD295, MRI_96, CERF98, ECH498, HAD300 AND PCM_00. The A1B, A2, B1 and B2 SRES scenarios considered in the present study are those obtained from AIM model. AIM has been selected for the present study since it examines the global warming response measures in Asia-Pacific region.

The present study lays emphasis on the effects of Indian emissions on global projections. The SCENGEN model outputs generated for the years 2020, 2050 and 2100 for various parameters are discussed below for global scale and for the Indian region extracted from the global values. The seasonal values for Indian region are also discussed in detail here for better understanding of model simulation for Indian region.

(A) Global Scale Results

4B.1 Change in global annual mean temperature and precipitation and actual temperature and precipitation

The global outputs for changes in annual mean temperature and precipitation along with the actual annual temperature and actual annual precipitation for P50 band of scenarios (default scenario) and for the modified BCS P50 scenario for the years 2020, 2050 and 2100 are as shown in Figure 4.14 and tables 18, 19, 20, 21. The P50 bands of scenarios have been considered since P50 is the median of all SRES scenarios. The outputs of modified scenarios BAU P50 and ECONOMY P50 have not been included in the figures in this chapter as the ranges for changes in annual mean temperature and precipitation along with the actual annual temperature and actual annual precipitation for all the modified scenarios are more or less similar and hence display the same range of the legend as evident from the values provided in respective tables in 'Appendix' section of this thesis. Again, since the values of BCS P50 scenario lies in between BAU P50 and ECONOMY P50 modified scenarios, so outputs of BCS P50 scenarios have been chosen to be displayed along with default P50 scenario for the sake of comparison. The results obtained have been discussed under four sub-sections as follows:

4B.1.1 Change in global annual mean temperature

This sub-section discusses the regional and global range values for changes in annual mean temperature for default P50 scenario and modified BCS P50 scenario for the years 2020, 2050 and 2100 (Figure 4.14, Table 17) for different regions like Asia, Africa, Australia, Europe, North America, South America and global scale.

The changes in global annual mean temperature for Asia for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range 0.4 to1.2°C, 0.9 to 3.2°C and 2.3 to 5.7°C respectively. For default P50 scenario the temperature range is 0.4 to 1.3°C for the year *2020, 1.2 to 3.5°C for the year 2050 and 2.4 to 6.6°C for the year 2100.*

For Africa, the changes in global annual mean temperature as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range 0.4 to 1.1°C, 1.1 to 2.6°C and 2.4 to 4.2°C respectively. For default P50 scenario the temperature range is 0.4 to 1.2°C for the year 2020, 1.2 to 2.7°C for the year 2050 and 2.6 to 4.6°C for the year 2100.

BCS P50 scenario range for changes in global annual mean temperature for Australia are 0.4 to 0.6°C, 1.0 to 1.6°C and 2.3 to 3.6°C respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 0.5 to 0.6°C for year 2020, 1.1 to 1.7°C for year 2050 and 2.5 to3.8°C for year 2100.

The changes in global annual mean temperature for Europe for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range 0.5 to 1.2°C, 1.3 to 2.6°C and 2.2 to 3.8°C respectively. For default P50 scenario the temperature range is 0.5 to 1.3°C for the year 2020, 1.4 to 2.8°C for the year 2050 and 2.2 to 4.2°C for the year 2100.

For North America, the changes in global annual mean temperature as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range 0.3 to 1.4°C, 1.0 to 3.2°C and 2.3 to 5.7°C respectively. For default P50 scenario the temperature ranges are 0.3 to 1.5°C for the year 2020, 1.1 to 3.4°C for the year 2050 and 2.7 to 6.3°C for the year 2100.

BCS P50 scenario range for changes in global annual mean temperature for South America are 0.1 to 0.7°C, 0.4 to 1.8°C and 1.4 to 3.5°C respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 0.1 to 0.7°C for the year 2020, 0.5 to 2.0°C for the year 2050 and 1.5 to 3.8°C for the year 2100.

Moreover, the change in annual global mean temperature for the modified scenario BCS P50 respectively for the years 2020, 2050 and 2100 are -0.3 to 1.7°C, -0.1 to 4.1°C and 0.5 to 7.5°C and the global mean temperature change is found to be 0.5, 1.3 and 2.8°C respectively for 2020, 2050 and 2100. The change in global annual mean temperature for default P50 scenario for years 2020, 2050 and 2100, respectively, have been found to be in the range of -0.3 to 1.8°C, -0.1 to 4.4°C and 0.6 to 8.1°C. Also, change in global mean temperature for default P50 scenario has been found to be 0.5°C for the year 2020, 1.4°C for year 2050 and 3.0°C for year 2100.

4B.1.2 Actual global annual mean temperature

This subsection gives the regional and global range values for actual global annual temperature for default P50 scenario and modified BCS P50 scenario for the years 2020, 2050 and 2100 (Figure 4.14, Table 18) for the regions mentioned above.

The actual global annual mean temperatures for Asia for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range -17.8 to 27.8°C, -16.3 to 29.2°C and -3.8 to 31.4°C respectively. For default P50 scenario the temperature ranges are -17.7 to 27.9°C for the year 2020, -16.1 to 29.3°C for the year 2050 and -13.4 to 31.7°C for the year 2100.

For Africa, the actual global annual mean temperatures as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range 17.9 to 29.9°C, 17.7 to 31.1°C and 19.4 to 33.1°C respectively. For default P50 scenario the temperature ranges are 16.9 to 29.1°C for the year 2020, 17.9 to 31.2°C for the year 2050 and 19.6 to 33.3°C for the year 2100.

BCS P50 scenario range for actual global annual mean temperatures for Australia are 13.9 to 27.5°C, 14.6 to 28.4°C and 15.9 to 30.2°C respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 14.0 to 27.5°C for the year 2020, 14.7 to 28.5°C for the year 2050 and 16.1 to 30.4°C for the year 2100.

The actual global annual mean temperatures for Europe for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range -0.4 to 17.5°C, 0.9 to 18.9°C and 2.4 to 20.5°C respectively. For default P50 scenario the temperature ranges are -0.3 to 17.6°C for the year 2020, 6.0 to 18.8°C for the year 2050 and 2.7 to 20.8°C for the year 2100.

For North America, the actual global annual mean temperatures as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lie in the range -25.6 to 26.5°C, -24.1 to 26.8°C and -21.6 to 28.4°C respectively. For default P50 scenario the temperature ranges are -25.6 to 26.6°C for the year 2020, -23.9 to 26.9°C for the year 2050 and -21.3 to 28.5°C for the year 2100.

BCS P50 scenario range for actual global annual mean temperatures for South America are 6.6 to 27.6°C, 7.1 to 28.8°C and 7.6 to 30.6°C respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 6.9 to 27.7°C for the year 2020, 6.6 to 28.9°C for the year 2050 and 7.7 to 30.9°C for the year 2100.

Moreover, the actual global annual mean temperatures for the modified scenario BCS P50 respectively for the years 2020, 2050 and 2100 are -58.3 to 29.9°C, -57.4 to 31.1°C and -55.7 to 33.1°C. However, the actual global annual temperatures for default P50 scenario for years 2020, 2050 and 2100, respectively are -58.2 to 29.9°C, -57.3 to 31.2°C and -55.5 to 3.4°C.

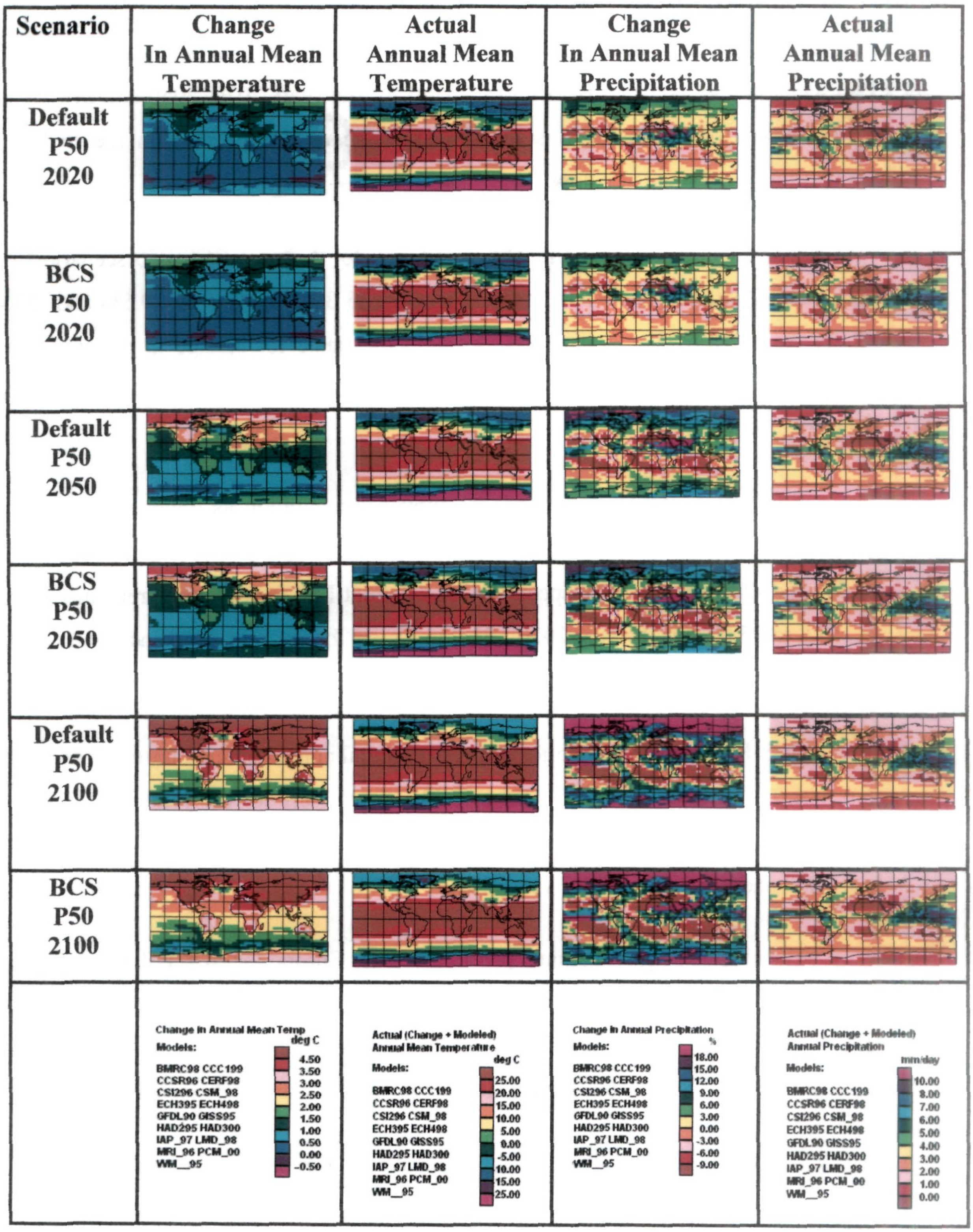

Figure 4.14 Change and actual annual global mean temperature and precipitation, during 2020-2100 period incorporating aerosol effects.

4B.1.3 Change in global annual precipitation

The regional and global range values for change in global annual precipitation for default P50 scenario and modified BCS P50 scenario for the years 2020, 2050 and 2100 (Figure 4.14, Table 19) for the regions mentioned above are obtained from the SCENGEN simulations are discussed below:

The change in global annual precipitation for Asia for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range -8.5 to 35.7%, -17.5 to 70.5% and -23.4 to 25.9% respectively. For default P50 scenario the range for change in precipitation are -2.2 to 36.9% for the year 2020, -18.3 to 74.2% for the year 2050 and -24.0 to 104.5% for the year 2100.

For Africa, the change in global annual precipitation as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range -15.5 to 33.9%, -20.7 to 17.5% and -28.7 to 104.1% respectively. For default P50 scenario the precipitation range is -15.6 to 35.0% for the year 2020, -21.9 to 18.0% for the year 2050 and -34.6 to 58.5% for the year 2100.

BCS P50 scenario range for change in global annual precipitation for Australia is -6.6 to 4.0%, -9.9 to 3.1% and -15.5 to 3.5% respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from -5.3 to 3.9% for year 2020, -10.6 to 3.0% for year 2050 and -20.2 to 0.9% for year 2100.

The change in global annual precipitation for Europe for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range -6.7 to 4.8%, -15.8 to 10.0% and -27.4 to 18.1% respectively. For default P50 scenario the precipitation range is -7.0 to 4.9% for the year 2020, -16.8 to 10.6% for the year 2050 and -28.7 to 15.9% for the year 2100.

For North America, the change in global annual precipitation as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range -8.6 to 7.9%, -11.2 to 17.3% and -13.4 to 31.6% respectively. For default P50 scenario the precipitation range is -8.3 to 8.3% for the year 2020, -11.5 to 17.9% for the year 2050 and -12.0 to 34.2% for the year 2100.

BCS P50 scenario range for change in global annual precipitation for South America is -9.1 to 17.1%, -16.3 to 9.9% and -20.7 to 14.9% respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from -9.0 to 7.1% for year 2020, -16.2 to 9.8% for year 2050 and -18.0 to 15.9% for year 2100.

Moreover, the changes in global annual precipitation for the modified scenario BCS P50 respectively for the years 2020, 2050 and 2100 are -15.5% to 35.7%, -20.7% to 70.5% and -28.7% to 112.0%. Model output shows the change in global annual precipitation to be 0.49%, 1.30% and 2.78% for 2020, 2050 and 2100 respectively. Thus the changes in global annual precipitation for default P50 scenario for years 2020, 2050 and 2100, respectively have been found to be in the range of -15.6% to 36.9%, -21.9% to 74.2% and -34.6% to 104.5%.

4B.1.4 Actual global annual precipitation

This subsection discusses the regional and global range values for actual global annual precipitation for default P50 scenario and modified BCS P50 scenario for the years 2020, 2050 and 2100 (Figure 4.14, Table 20) for the regions mentioned earlier.

The actual global annual precipitation for Asia for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range 0.1 to 9.3 mm/day, 0.1 to 9.3 mm/day and 0.1 to 9.3 mm/day respectively. For default P50 scenario the precipitation range is 0.1 to 9.3 mm/day for the year 2020, 0.1 to 9.3 mm/day for the year 2050 and 0.1 to 9.4 mm/day for the year 2100.

For Africa, the actual global annual precipitation as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range 0.0 to 6.1 mm/day, 0.0 to 6.3 mm/day and 0.2 to 6.6 mm/day respectively. For default P50 scenario the precipitation range is 0.0 to 6.2 mm/day for the year 2020, 0.0 to 6.3 mm/day for the year 2050 and 0.0 to 6.5 mm/day for the year 2100.

BCS P50 scenario range for actual global annual precipitation for Australia is 0.5 to 4.6 mm/day, 0.5 to 4.5 mm/day and 0.4 to 3.7 mm/day respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 0.5 to 4.6 mm/day for year 2020, 0.5 to 4.5 mm/day for year 2050 and 0.5 to 4.5 mm/day for year 2100.

The actual global annual precipitation for Europe for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range 0.9 to 3.2 mm/day, 0.8 to 3.4 mm/day and 0.9 to 3.2 mm/day respectively. For default P50 scenario the precipitation range is 0.9 to 3.2 mm/day for the year 2020, 0.8 to 3.4 mm/day for the year 2050 and 0.7 to 3.5 mm/day for the year 2100.

For North America, the actual global annual precipitation as obtained for BCS P50 scenario for the year 2020, 2050 and 2100 lies in the range 0.2 to 4.5 mm/day, 0.2 to 6.1 mm/day and 0.2 to 8.7 mm/day respectively. For default P50 scenario the precipitation range is 0.2 to 4.5 mm/day for the year 2020, 0.2 to 4.5 mm/day for the year 2050 and 0.2 to 4.8 mm/day for the year 2100.

BCS P50 scenario range for actual global annual precipitation for South America is 0.6 to 8.3 mm/day, 0.6 to 8.6 mm/day and 0.6 to 8.7 mm/day respectively for the years 2020, 2050 and 2100. The default P50 scenario ranges from 0.6 to 8.3 mm/day for year 2020, 0.6 to 8.6 mm/day for year 2050 and 0.6 to 8.4 mm/day for year 2100.

The actual global annual precipitation for the modified scenario BCS P50 respectively for the years 2020, 2050 and 2100 are projected to be 0.0 to 10.0 mm/day, 0.0 to 9.7 mm/day and 0.0 to 10.7 mm/day by SCENGEN. While the actual global annual precipitation for default P50 scenario for years 2020, 2050 and 2100, respectively is 0.0 to 10.0 mm/day, 0.0 to 9.7 mm/day and 0.0 to 11.1 mm/day.

(B) Results for Indian region

Since the present study intended to investigate the impact of Indian energy emissions on global climatic parameters, so the model outputs for Indian region have also been extracted from the obtained global values although this process has large inherent uncertainties.

Figure 4.14 displays the global projections for all the regions. From the global projections, Indian projections have been isolated. The map outputs for Indian region for changes in global annual mean temperature and precipitation and actual annual temperature and actual annual precipitation for all the default and modified scenarios viz., P50 band of scenarios, A1B band of scenarios, A2 band of scenarios, B1 band of scenarios and B2 band of scenarios which are shown in figures 4.15, 4.16, 4.17 and 4.18 and discussed in following sub-sections.

4B.2 Change in annual mean temperature over Indian region

An overall increase in the change in annual mean temperature (°C) has been observed for the period from 2020-2100 for all the scenarios under all the three approaches (Figure 4.15, Table 21). This is in accordance with the results obtained from HadRM2 carried out earlier (Rupa Kumar et al., 2003, 2006) for Indian region.

Year 2000 is the starting year for simulation in the present study and hence the temperature change for this year is constant in the range of 0.1 to 0.3°C for all the scenarios. The highest change in temperature occurs for the northern states for the years 2020, 2050 and 2100. For the year 2020, P50 band of scenarios indicate a temperature change ranging from 0.3 to 1.0°C for the default P50 scenario to 0.3 to 0.9°C for the modified P50 scenarios, A1B band of scenarios indicate a temperature change ranging from 0.3 to 0.9°C for the default A1B scenario to 0.3 to 0.7°C for the modified A1B scenarios, A2 band of scenarios indicate a temperature change ranging from 0.3 to 0.7°C for the default A2 scenario and 0.3 to 0.7°C for the modified A2 scenarios, B1 band of scenarios indicate a temperature change ranging from 0.3 to 0.8°C for all the four B1 band of scenarios with similar range exhibited by the B2 band of scenarios.

For 2050, the projected temperature change for all scenarios lies in the range from 1.0 to 2.6°C for default P50 scenario and 0.9 to 2.4°C for modified P50 scenarios BAU P50, BCS P50 and ECONOMY P50. For A1B band of scenarios, the default A1B scenario indicate a temperature change ranging from 1.3 to 2.5°C and the modified A1B scenarios indicate a temperature change ranging from 1.2 to 2.3°C. A2 band of scenarios indicate a temperature change ranging from 0.8 to 1.7°C for default A2 scenario to 0.7 to 1.6°C for all the modified A2 scenarios. The default B1 scenario indicates a temperature change ranging from 1.1 to 2.4°C and the modified B1 scenarios indicate a temperature change from 1.0 to 2.3°C. For the default B2 scenario, temperature change ranges from 1.1 to 2.6°C and the change in temperature for the modified B2 scenarios ranges from 1.0 to 2.4°C.

Similarly, for the year 2100, the P50 band of scenarios indicate a temperature change ranging from 2.5 to 5.0°C and for the modified P50 scenarios the change in temperature ranges from 2.4 to 4.7°C. Default A1B scenario indicate a temperature change ranging from 2.2 to 4.6°C while the range of temperature change for modified A1B scenarios is 2.1 to 4.5°C. For the default A2 scenario, the range of change in temperature is 2.6 to 4.6°C, and the range of change in temperature for A2 band of scenarios is 2.4 to 4.2°C. Default B1 scenario indicate a range of change in temperature of 1.7 to 3.8°C and the range of change in temperature for modified B1 scenarios is 1.6 to 3.7°C. Also, the default B2 scenario shows the range of change in temperature to be 2.2 to 4.6°C and the range of change in temperature for modified B2 scenarios is 2.1 to 4.3°C.

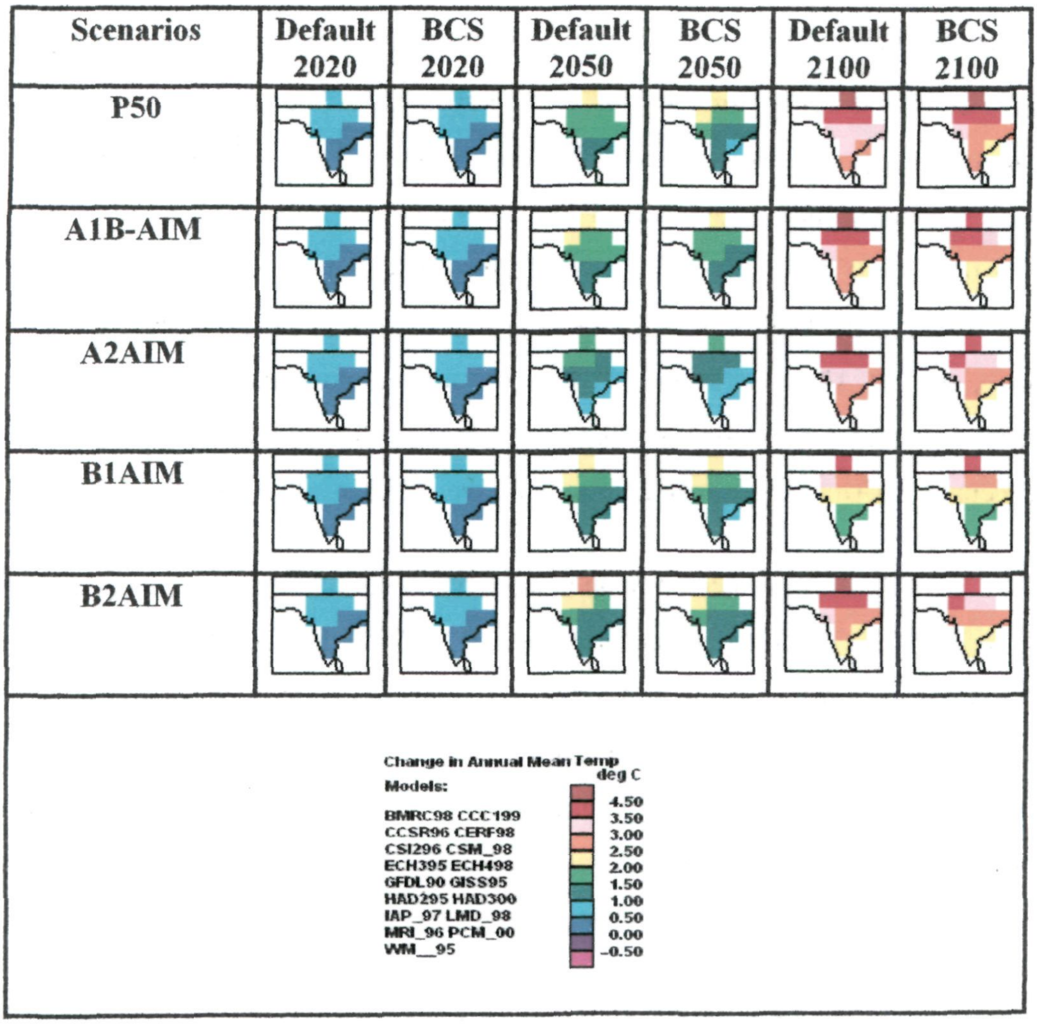

Figure 4.15. Change in annual mean temperature (°C) during 2020-2100 period for Indian region incorporating aerosol effects

It is observed from these projections that north India will experience greater change in temperature as compared to the rest of the country in future. Central India is projected to experience a change from 0.5 to 2.0°C for the year 2050 and 2.0 to 3.5°C in the year 2100. The B1 band of scenarios shows smallest change while P50 band indicates highest change in the projected temperature changes. Southern India is expected to experience least change in the temperature during the 21st century as projected by present modeling study.

4B.3 Change in annual precipitation over Indian region

The change in temperature as indicated by the above results would also result in the change in precipitation pattern in Indian region (Figure 4.16, Table 22). This is in accordance with the results obtained from HadRM2 earlier (Rupa Kumar et al., 2003, 2006). Results of the simulations conducted in the study indicate that maximum changes in precipitation might occur in the northern states while minimum changes might occur in the southern states. A2 band of scenarios exhibit the greatest changes for all the projected years while B2 band of scenarios indicate least change. The pattern of changes in annual precipitation seems to have strong correlation with the changes in temperature.

For the year 2020, default P50 scenario indicates a precipitation change in the range -0.7% to 18.6% and the modified P50 scenarios indicate a precipitation change in the range -0.8% to 18.2%. The ranges for change in precipitation for default A1B scenario, default A2 scenario, default B1 scenario and default B2 scenario, respectively are, 2.1% to 24.5%, 3.4% to 24.2%, -0.3% to 21.0% and -1.9% to 18.6%. However, for the modified A1B scenarios, modified A2 scenarios, modified B1 scenarios and modified B2 scenarios, the precipitation change ranges from 2.0%to 23.9%, 3.3% to 23.6% and -0.4% to 20.6% respectively.

For 2050, the projected precipitation change for default P50 scenario is 0.7% to 30.9% and 0.4% to 30.1% for modified P50 scenarios (i.e. BAU P50, BCS P50 and ECONOMY P50). For A1B band of scenarios, the default A1B scenario indicate a precipitation change ranging from 4.7% to 19.4% and the modified A1B scenarios indicate a precipitation change ranging from 4.2% to 18.1%. A2 band of scenarios indicate a precipitation change ranging from 7.1% to 51.4% for default A2 scenario while 6.7% to 50.0% for all the modified A2 scenarios. The default B1 scenario indicates a precipitation change ranging from -2.0% to 22.2% and the modified B1 scenarios indicate a precipitation change from -2.3% to 21.6%. For the default B2 scenario, precipitation change ranges from -1.5% to 22.5% and the range of change in precipitation for the modified B2 scenarios is -1.8% to 33.4%.

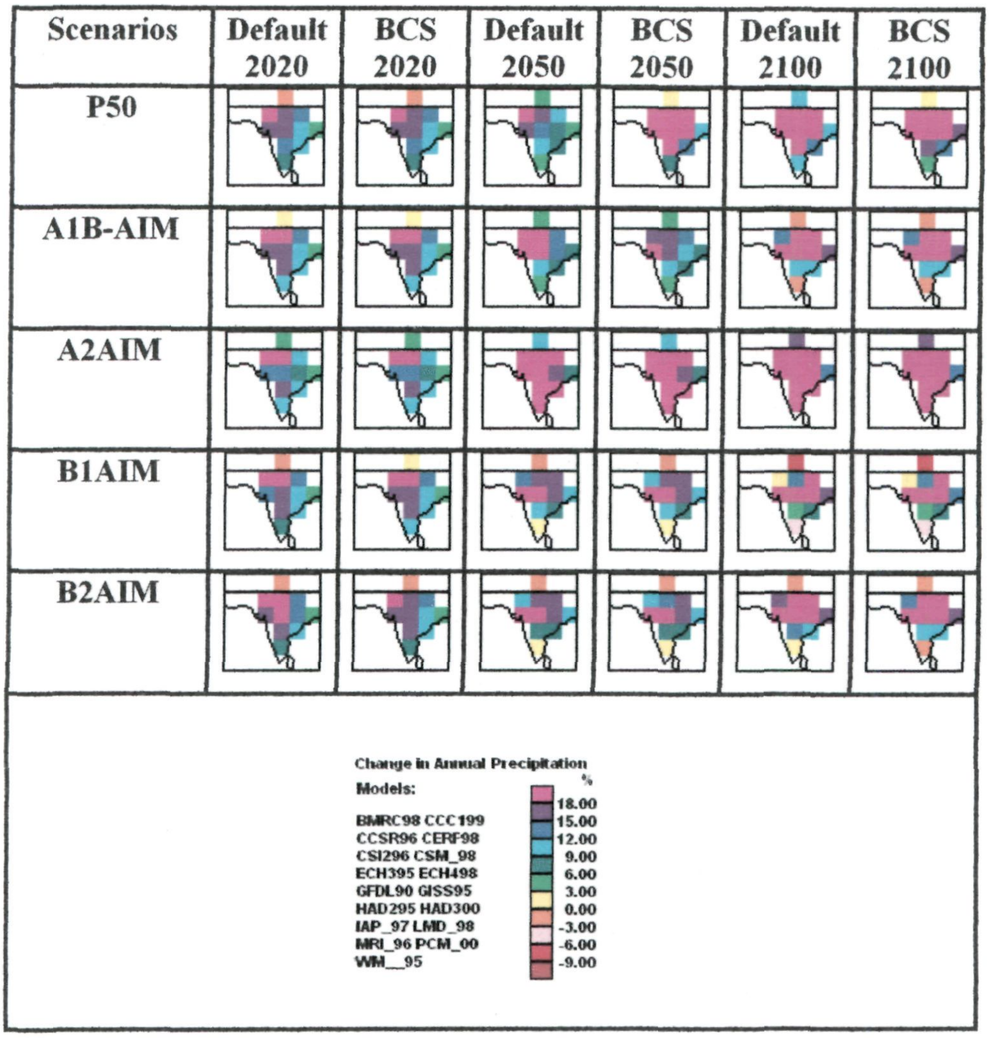

Figure 4.16 Change in annual global precipitation (%) for Indian region during 2020-2100 period incorporating aerosol effects

Similarly, for the year 2100, the default P50 scenario indicates a precipitation change from 2.3% to 38.5% and for the modified P50 scenarios, the change in precipitation is from 1.6 to 36.9%. Default A1B scenario indicates a precipitation change ranging from -2.1% to 35.6% and the range of precipitation change for modified A1B scenarios is -2.7% to 34.6%. For the default A2 scenario, the range of change in precipitation is 13.3% to 58.6%, and the range of change in precipitation for A2 band of scenarios is 12.4% to 56.2%. Default B1 scenario indicates a range of change in precipitation of -7.3% to 28.9% and the range of change in precipitation for modified B1 scenarios is -7.6% to 28.7%. Also, the default B2 scenario shows the range of change in precipitation to be -1.4% to 34.5% and the range of change in precipitation for modified B2 scenarios is -2.1% to 33.4%.

4B.4 Actual annual temperature over Indian region

Knowing the changes in temperature, the actual annual mean temperature for all the scenarios (Figure 4.17, Table 23) have been derived and it has been found that the actual temperature which is basically the sum of modeled and change in temperature is approximately same for all scenarios for the same year.

For the year 2020, the actual annual mean temperature for default A1B scenario ranges from 7.5 to 27.7°C. For BAU A1B scenario, BCS A1B scenario and ECONOMY A1B scenario, the actual annual mean temperature ranges from 7.4 to 27.6°C. For the A2 band of scenarios the range of actual annual mean temperature for the year 2020 ranges from 7.3 to 27.7°C. For default B1 scenario actual annual mean temperature ranges from 7.4 to 27.7°C and for scenarios like BAU B1, BCS B1, ECONOMY B1, the actual annual mean temperature ranges from 7.5 to 27.6°C. The actual annual mean temperature for B2 band of scenarios ranges from 7.5 to 27.6°C. For default P50 scenario the actual annual mean temperature ranges from 7.6 to 27.7°C and for BAU P50 scenario, BCS P50 scenario, ECONOMY P50 scenario the actual annual mean temperature ranges from 7.5 to 27.6°C.

For the year 2050, the actual annual mean temperature for default A1B scenario ranges from 9.0 to 28.7°C, for BAU A1B scenario, BCS A1B scenario and ECONOMY A1B scenario the actual annual mean temperature ranges from 8.9 to 28.6°C. For the default A2 scenario actual annual mean temperature for the year 2050 lies in the range 8.3 to 28.2°C and for BAU A2 scenario, BCS A2 scenario it extends from 8.2 to 28.1°C and for ECONOMY A2 scenario the actual annual mean temperature extends from 8.1 to 27.9°C. For default B1 scenario, actual annual mean temperature ranges from 9.0 to 28.4°C and for BAU B1 scenario, BCS B1 scenario and ECONOMY B1 scenario the actual annual mean temperature ranges from 8.9 to 28.4°C. The actual annual mean temperature for default B2 scenario ranges from 8.7 to 28.3°C, for BAU B2 scenarios the temperature ranges from 9.1 to 28.4°C and for the BCS B2 and ECONOMY B2 scenarios the annual actual mean temperature ranges from 9.0 to 28.4°C. For default P50 scenario the actual annual mean temperature ranges from 9.2 to 28.4°C and for BAU P50 scenario, BCS P50 scenario, ECONOMY P50 scenario the actual annual mean temperature ranges from 9.0 to 28.3°C.

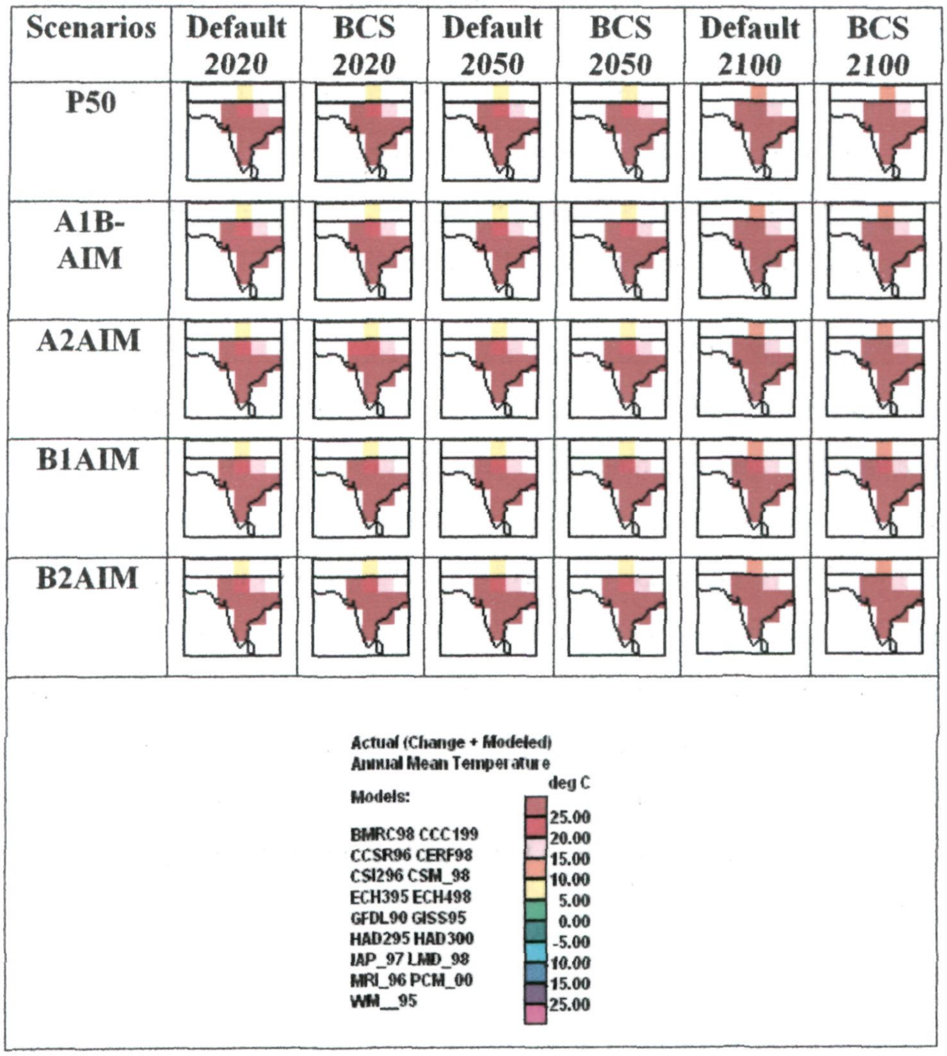

Figure 4.17 Actual annual global mean temperature (°C) during 2020-2100 period over Indian region incorporating aerosol effects.

For the year 2100, the actual annual mean temperature for default A1B scenario ranges from 11.3 to 29.8°C, for BAU A1B scenario, BCS A1B scenario and ECONOMY A1B scenario the actual annual mean temperature ranges from 11.1 to 29.6°C. For the default A2 scenario actual annual mean temperature for the year 2100 lies in the range 11.2 to 30.0°C, for BAU A2 scenario, the actual annual mean temperature extends from 10.9 to 29.8°C, for the BCS A2 scenario it extends from 10.8 to 29.7°C and for ECONOMY A2 scenario the actual annual mean temperature lies in the range of 10.8 to 29.8°C. For default B1 scenario, actual annual mean temperature ranges from 10.4 to

29.1°C, for BAU B1 scenario, the temperature range is 10.4 to 29.1°C, for BCS B1 scenario, actual annual temperature varies from 9.2 to 29.0°C and for ECONOMY B1 scenario the actual annual mean temperature ranges from 9.3 to 29.0°C. The actual annual mean temperature for default B2 scenario ranges from 10.9 to 30.0°C, for BAU B2 scenario the temperature ranges from 10.2 to 29.6°C, for the BCS B2 scenario the temperature ranges from 10.1 to 29.5°C and for ECONOMY B2 scenario the temperature varies from 10.1 to 29.6°C. For default P50 scenario the actual annual mean temperature ranges from 10.9 to 30.0°C and for BAU P50 scenario and ECONOMY P50 scenario the actual annual mean temperature ranges from 10.7 to 29.9°C.

4B.5 Actual annual precipitation over Indian region

The annual actual mean precipitation outputs (Figure 4.18, Table 24) for the year 2020, lies in the range of 0.9 to 4.5 mm/day. For 2050, annual actual mean precipitation ranges from 0.8 to 5.0 mm/day and for the year 2100, annual actual mean precipitation ranges from 0.7 to 4.9 mm/day.

For the year 2020, the actual annual mean precipitation for A1B band of scenarios, A2 band of scenarios and B1 band of scenarios range from 0.9 to 4.5 mm/day. For B2 band of scenarios and P50 band of scenarios, the actual annual mean precipitation ranges from 0.9 to 4.4 mm/day.

For the year 2050, the actual annual mean precipitation for A1B band of scenarios ranges from 0.9 to 4.5 mm/day. For the default A2 scenario and BAU A2 scenario, actual annual mean precipitation for the year 2050 lies in the range 1.1 to 5.0 mm/day. For BCS A2 scenario and ECONOMY A2 scenario the actual annual mean precipitation lies in the range of 1.1 to 4.9 mm/day. For B1 band of scenarios, actual annual mean precipitation ranges from 0.8 to 4.2 mm/day. The actual annual mean precipitation for the B2 band of scenarios ranges from 0.8 to 4.1 mm/day and the actual annual mean precipitation for P50 band of scenarios ranges from 0.9 to 4.4 mm/day.

For the year 2100, the actual annual mean precipitation for A1B band of scenarios ranges from 0.8 to 4.1 mm/day. For the A2 band of scenarios, actual annual mean precipitation for the year 2050 lies in the range 1.1 to 4.9 mm/day. For B1 band of scenarios, actual annual mean precipitation ranges from 0.7 to 3.9 mm/day. The actual annual mean precipitation for the B2 band of scenarios ranges from 0.8 to 4.1 mm/day and the actual annual mean precipitation for P50 band of scenarios ranges from 0.9 to 4.3 mm/day.

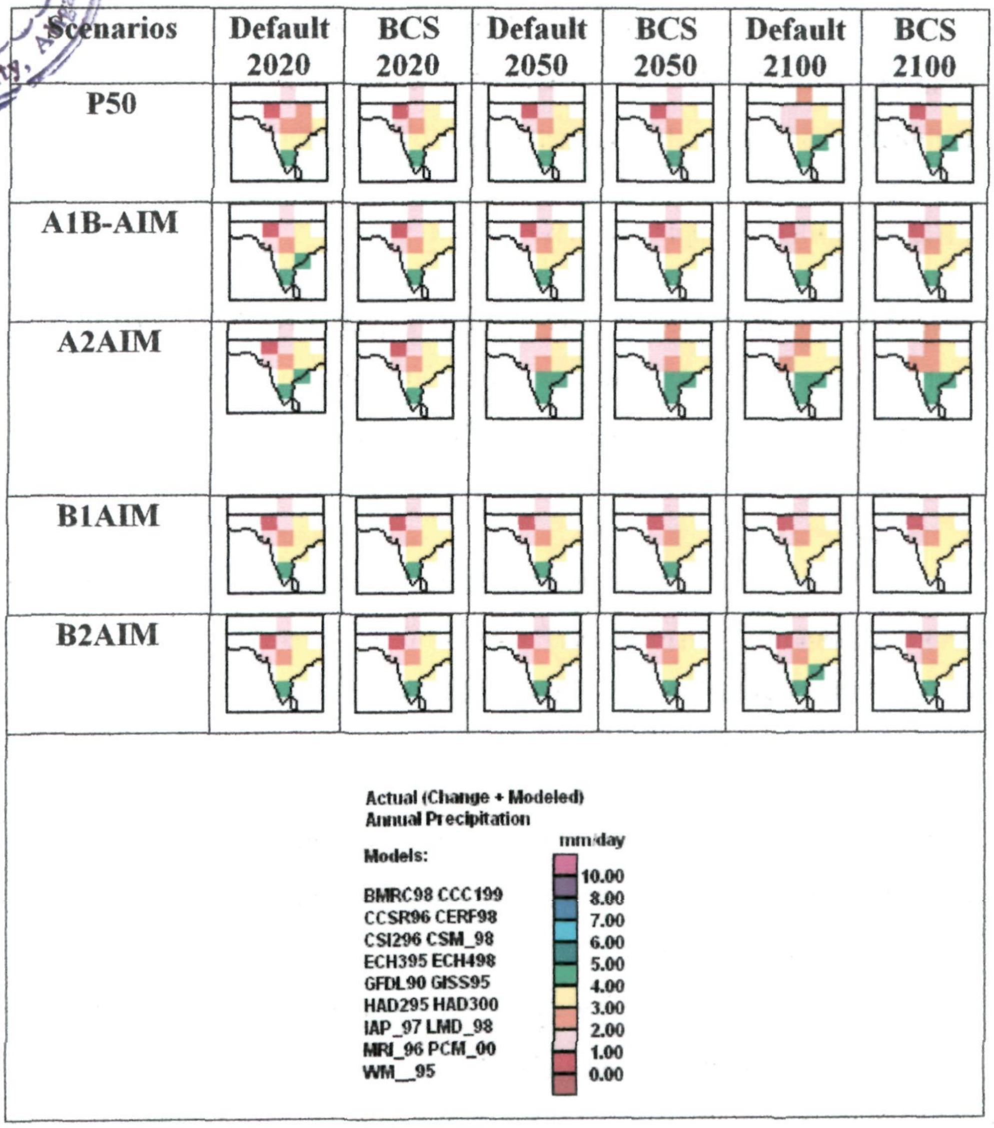

Figure 4.18 Actual annual global precipitation (mm/day) during 2020-2100 over Indian region period incorporating aerosol effects

(C) Results for seasonal variations for Indian region

In Indian sub-continent, the monsoon system is the most dominant meteorological phenomenon, which influences the eco-system, agriculture and economy of the region. The summer monsoon and winter monsoon are the two major sub-systems of Indian monsoon system. The SCENGEN model outputs have also been generated for seasonal variation for Indian region to get the projections for the monsoon precipitation. The four seasons have been divided to cover months of December, January, February (DJF); March, April, May (MAM); June, July, August (JJA; covering the monsoon period) and September, October, November (SON; covering the winter monsoon period). The outputs for seasonal changes in temperature and precipitation, and also actual temperature and precipitation have been generated for modified P50 band of scenarios. The P50 scenario was considered since it is the median of all the thirty-five SRES scenarios.

4B.6 Seasonal change in temperature for P50 band of scenarios over Indian region

Seasonal change in temperature for P50 band of scenarios over Indian region is shown in Figure 4.19 (Table 25). The salient features are discussed below:

1. December, January and February period: For the year 2020, the mean temperature change ranges from 0.5 to 1.3°C for the P50 band of scenarios for DJF months. For the year 2050, temperature change ranges from 1.3 to 2.8°C for the default P50 scenario and from 1.3 to 2.7°C for BAU P50 scenario. For the BCS P50 and ECONOMY P50 scenarios the temperature change lies in the range of 1.2 to 2.7°C and 1.2 to 2.6°C respectively. The temperature change for the year 2100 lies in the range 2.9 to 4.3°C for default P50 scenario and for BCS P50 and ECONOMY P50 scenarios the range is 2.7 to 4.7°C. However, BCS P50 scenario lies in the range of 2.7 to 4.1°C.

2. March, April and May period: For the year 2020, change in temperature ranges from 0.5 to 1.1°C for the P50 band of scenarios. For the year 2050, change in temperature ranges from 1.5 to 3.0°C for the default P50 scenario and from 1.4 to 2.8°C for BAU P50, BCS P50 and ECONOMY P50 scenarios. The change in temperature for the year 2100 lies in the range 3.0 to 4.7°C for default P50 scenario and for BAU P50 the range is 2.9 to 4.4°C. BCS P50 scenario indicates the temperature change ranging from 2.8 to 4.3°C and ECONOMY P50 scenario depicts the change in temperature to lie in the range 2.8 to 4.4°C.

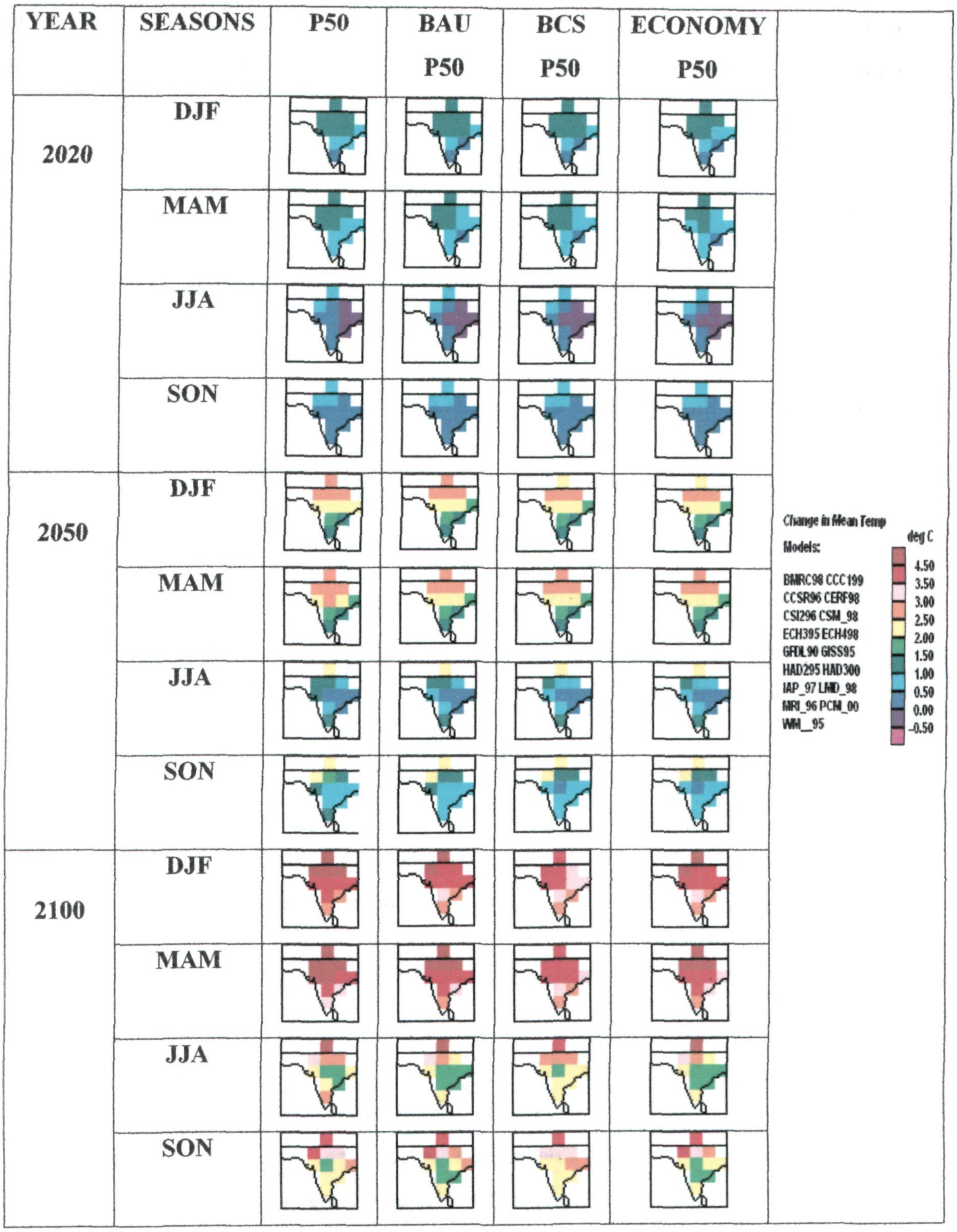

Figure 4.19 Seasonal change in temperature (°C) for P50, BAU P50, BCS P50 and ECONOMY P50 scenarios over Indian region

3. June, July and August period: For the year 2020, change in temperature ranges from -0.2 to 0.9°C for the default P50 scenario, BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario. For the year 2050, change in temperature ranges from 0.2 to

2.5°C for the default P50 scenario and modified BCS P50 scenario. For BAU P50 and ECONOMY P50 it ranges from 0.2 to 2.4°C. The change in temperature for the year 2100 lie in the range of 2.1 to 4.3°C for default P50 scenario. For BAU P50 scenario the range is 2.0 to 4.1°C for the year 2100. BCS P50 scenario and ECONOMY P50 scenario depicts the change in temperature in the range of 1.8 to 4.8°C and 1.8 to 4.6°C, respectively, for the year 2100.

4. September, October, November: For the year 2020, change in temperature ranges from 0.1 to 0.9°C for the whole P50 band of scenarios. For the year 2050, change in temperature ranges from 0.6 to 2.3°C for the default P50 scenario and from 0.5 to 2.2°C for BAU P50 scenario. The BCS P50 scenario and ECONOMY P50 scenario indicate that the change in temperature lies in the range of 0.5 to 2.1°C for the year 2050. The change in temperature for the year 2100 lies in the range 2.4 to 4.1°C for the default P50 scenario. The change in temperature for BAU P50 scenario and BCS P50 scenario lies in the range of 2.3 to 3.9°C for the year 2100. The ECONOMY P50 scenario indicates a range of 2.3 to 3.8°C for the year 2100.

4B.7 Seasonal change in precipitation for P50 band of scenarios over Indian region

The results for change in seasonal precipitation (Figure 4.20, Table 25) indicate a general increase in precipitation as one move from 2020 to 2100. This is observed for all the scenarios and for all the seasons. This goes in accordance with various reports of researchers, which indicate that with rise in precipitation owing to global warming, India will experience increase in precipitation. Season JJA, being the monsoon season experiences maximum precipitation followed respectively by SON, DJF and MAM. DJF months are the winter months and so corresponds with lower precipitation. This is well depicted from the outputs for all the years by the P50 band of scenarios. Precipitation increases from DJF to JJA and thereafter starts a decreasing trend from SON to DJF months.

As shown, the outputs for seasonal change in precipitation (Figure 4.20) indicate that the change in precipitation is maximum for JJA season for all the years and is minimum for DJF season. In JJA season, change is less in the extreme southern states as compared to rest of India. Corresponding effects of changes in JJA and DJF have been observed respectively in SON and MAM seasons.

The results for seasonal variations in mean temperature (Figure 4.19) as projected by SCENGEN outputs indicate that the change in temperature is minimum for the JJA season which is the summer monsoon season for all the years for which projections have been generated, that is, 2020, 2050 and 2100. During this season the eastern states and central states in India are projected to experience the least change in temperature, compared to the rest of India. The seasonal characteristics for change in precipitation for Indian region are discussed below:

1. December, January and February period: For the year 2020, change in precipitation ranges from -83.1 to -17.1 % for the default P50 scenario and from -83.0 to -17.7 % BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario. For the year 2050, change in precipitation ranges from -99.3 to 125.0 % for the default P50 scenario and from -98.7 to 124.9 % for the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario. The projections for actual precipitation for the year 2100 lie in the range -60.1 to 178.6 % for default P50 scenario. For the modified BAU P50 scenario and ECONOMY P50 scenario, the range of change in precipitation is -59.6 to 178.2 %. The BCS P50 scenario indicates a change in precipitation to lie between -59.5 to 178.1 %.

2. March, April and May period: For the year 2020, change in precipitation ranges from -53.9 to 40.5 % for the default P50 scenario, from -53.9 to 40.2 % for BAU P50 scenario. For BCS P50 scenario change in precipitation lies in the range of -53.8 to 40.2 % and for ECONOMY P50 scenario the change in precipitation lies in the ranges -53.8 to 40.1 %. For the year 2050, precipitation change ranges from -87.3 to 34.9 % for the default P50 scenario. For the modified BAU P50 scenario and BCS P50 scenarios the change in precipitation ranges from -87.1 to 34.7 %. ECONOMY P50 scenario shows a range of change in precipitation from -87.0 to 34.6 %. The actual precipitation for the year 2100 lies in the range of -8.4 % to 32.8 % for the default P50 scenario. For the modified BAU P50 scenario, the change in precipitation ranges from -7.9 to 31.1 %. For the BCS P50 scenario and ECONOMY P50 scenario change in precipitation for the year 2100, respectively lies in the range -7.8 to 30.4 % and -7.9 to 30.8 %.

3. June, July and August period: For the year 2020, projections for change in precipitation range from 9.5 to 71.9 % for the default P50 scenario. For BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario, precipitation change projections lie in the range of 9.4 to 71.3 %. For the year 2050, change in precipitation ranges from 10.4 to 100.3 % for the default P50 scenario, and 10.2 to 97.8 % for all the modified scenarios, viz BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario for the year 2050. The precipitation change, for the year 2100, lies in the range of 6.9 to 87.7 % for default P50 scenario. For the modified BAU P50 scenario, the range of precipitation change is 6.5 to 83.1 %. For the modified scenarios (viz. BCS P50 scenario and ECONOMY P50 scenario) change in precipitation for the year 2100, respectively, lies in the range of 5.6 to 110.3 % and 5.3 to 105.7 %.

4. September, October and November period: For the year 2020, projections for change in precipitation range from 0.9 to 33.9 % for the default P50 scenario, 0.8 to 33.4 % for BAU P50 scenario, 0.8 to 33.3 % for BCS P50 scenario and from 0.7 to 33.2 % for ECONOMY P50 scenario. For the year 2050, change in precipitation ranges from 9.0 to 53.8 % for the default P50 scenario, and for the modified scenarios BAU P50, BCS P50 and ECONOMY P50, change in precipitation lies in the range of 8.7 to 52.4 %, 8.6 to 52.1 % and 8.6 to 51.9 % respectively. The projections for change in precipitation for the year 2100 lie in the range 10.1 to 50.1 % for default P50 scenario. For the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario, projections of change in precipitation for the year 2100 lies in the range of 9.6 to 47.7 % for BAU P50 scenario, 9.4 to 46.5 % for BCS P50 scenario and 9.5 to 47.0 % for ECONOMY P50 scenario.

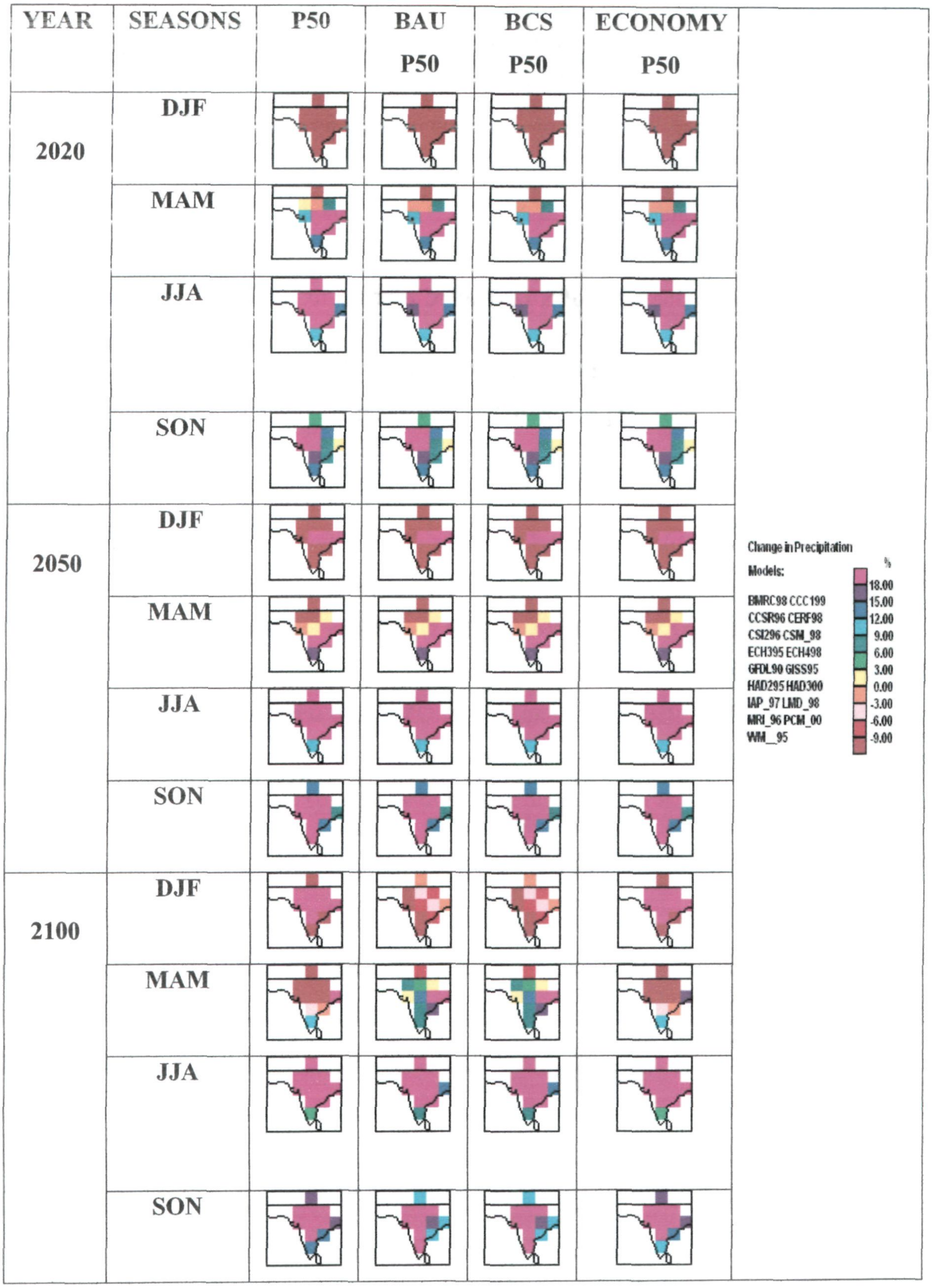

Figure 4.20 Seasonal change in precipitation (%) for P50, BAU P50, BCS P50 and ECONOMY P50 scenarios over Indian region

4B.8 Actual seasonal temperature of P50 band of scenarios over Indian region

The projections for actual seasonal average temperature (Figure 4.21, Table 26) for all the seasons appear to be the same. The main features observed from the simulations are discussed below:

1. December, January and February period: For the year 2020, actual seasonal temperature projection ranges from -4.4 to 25.2°C for the P50 band of scenarios. For the year 2050, actual seasonal temperature projection ranges from -2.8 to 26.1°C for the default P50 scenario and from -2.9 to 26.0°C for BAU P50 scenario. For the BCS P50 and ECONOMY P50 scenarios, the actual seasonal temperature projection lies in the range -3.0 to 26.0°C. The projected actual seasonal temperature for the year 2100 lies in the range -0.5 to 27.7°C for default P50 scenario, BAU P50 and ECONOMY P50 scenarios the range is -0.7 to 27.5°C. However, BCS P50 scenario projections lie in the range of -0.8 to 27.5°C.

2. March, April and May period: For the year 2020, actual seasonal temperature projection ranges from 7.3 to 31.7°C for the default P50 scenario. The modified BAU P50, BCS P50 and ECONOMY P50 scenarios show a temperature range of 7.3 to 31.6°C for the year 2020. For the year 2050, actual seasonal temperature projection ranges from 9.2 to 32.8°C for the default P50 scenario and from 9.0 to 32.7°C for BAU P50, BCS P50 and ECONOMY P50 scenarios. The projected actual seasonal temperature for the year 2100 lies in the range 10.9 to 34.5°C for default P50 scenario. The BAU P50 the range is 10.7 to 34.3°C. BCS P50 scenario indicates the actual seasonal temperature ranging from 11.6 to 34.5°C and ECONOMY P50 scenario depicts the actual seasonal temperature to lie in the range 11.7 to 34.5°C.

3. June, July and August period: For the year 2020, actual seasonal temperature projection ranges from 19.1 to 34.7°C for the default P50 scenario, BAU P50 scenario and BCS P50 scenario. ECONOMY P50 scenario shows the actual seasonal temperature to vary from 19.0 to 34.6°C for the year 2020. For the year 2050, actual seasonal temperature ranges from 20.6 to 35.6°C for the default P50 scenario and from 20.5 to 35.5°C for BAU P50, BCS P50 and ECONOMY P50 scenarios. The actual seasonal temperature for the year 2100 lies in the range of 22.5 to 37.1°C for default P50 scenario. For BAU P50 scenario the range is 22.3 to 36.9°C for the year 2100. BCS P50 scenario and ECONOMY P50 scenario depict the projected actual seasonal temperature to lie in the range of 22.7 to 37.1°C for the year 2100.

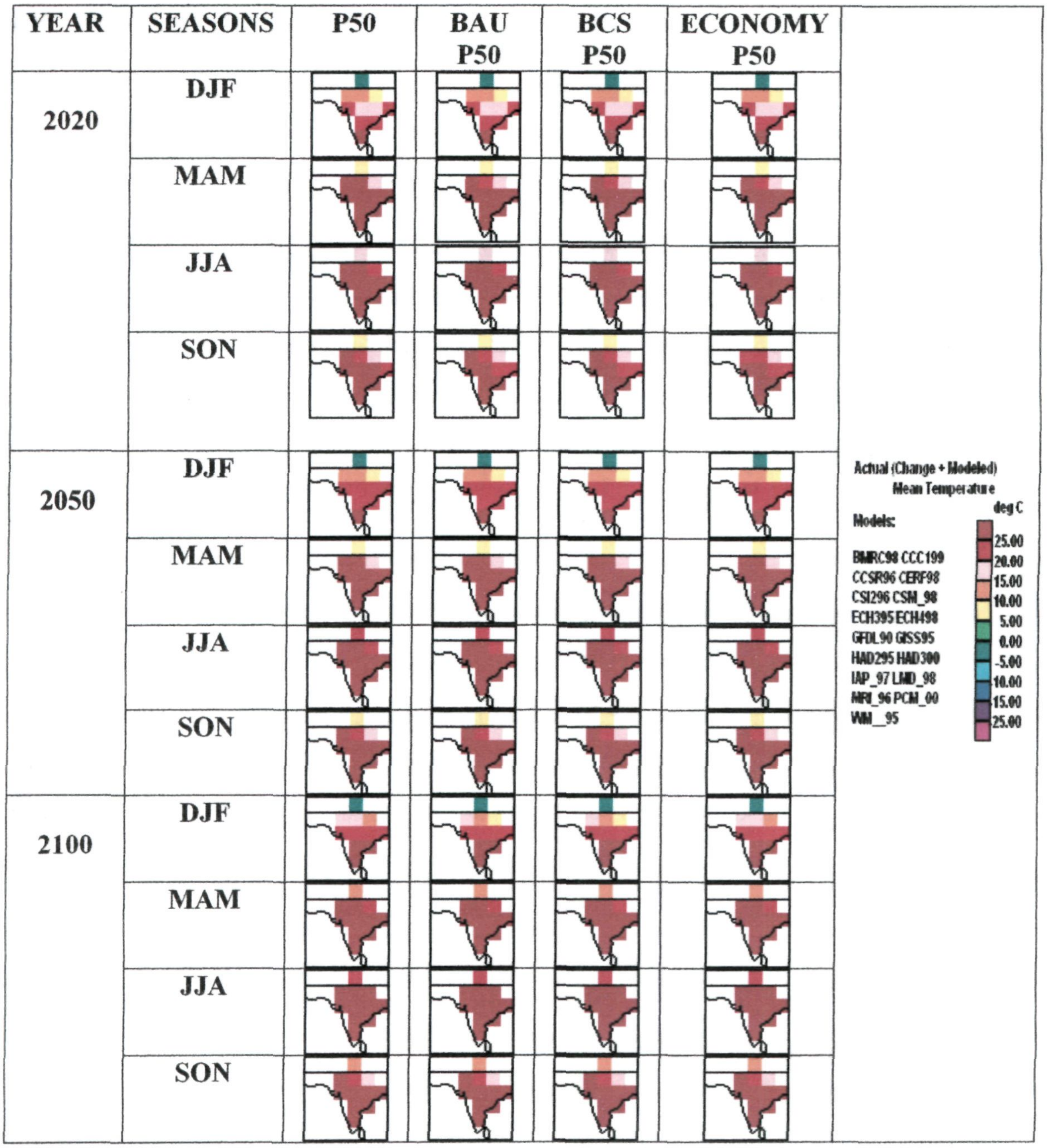

Figure 4.21 Actual seasonal temperature (°C) for P50, BAU P50, BCS P50 and ECONOMY P50 scenarios over Indian region.

4. September, October and November period: For the year 2020, actual seasonal temperature projection ranges from 8.3 to 27.4°C for the whole P50 band of scenarios. For the year 2050, actual seasonal temperature ranges from 9.7 to 28.1°C for the default P50 scenario and from 9.6 to 28.0°C for BAU P50 scenario and the BCS P50 scenario.

The ECONOMY P50 scenario indicates that the actual seasonal temperature would lie in the range of 9.5 to 28.0°C. The projected actual seasonal temperature for the year 2100 lies in the range 11.6 to 29.6°C for the default P50 scenario and BAU P50 scenario. The actual seasonal temperature for BCS P50 scenario lies in the range of 11.5 to 29.2°C for the year 2100. The ECONOMY P50 scenario indicates a range of 11.6 to 29.2°C for the year 2100.

4B.9 Actual Seasonal precipitation for P50 band of scenarios over Indian region

The results for the projected actual seasonal precipitation (Figure 4.22, Table 26) indicate a general increase in precipitation as one move from 2000 to 2100. This is observed for all the scenarios and for all the seasons. This is in accordance with various reports of researchers, which indicate that with rise in temperature owing to global warming, India will experience increase in precipitation. Season JJA, being the monsoon season experiences maximum precipitation followed by SON, DJF and MAM respectively. For Indian region, simulated seasonal precipitation features are discussed as below:

1. December, January and February period: For the year 2020, projected seasonal precipitation ranges from 0.2 to 1.7 mm/day for the P50 band of scenarios. For the year 2050, the projected seasonal precipitation ranges from -0.2 to 1.6 mm/day for the default P50 scenario and modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario. The projected seasonal precipitation for the year 2100 lies in the range of -0.6 to 1.6 mm/day for default P50 scenario and the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario.

2. March, April and May period: For the year 2020, seasonal precipitation projection ranges from 0.3 to 2.4 mm/day for the P50 band of scenarios. For the year 2050, seasonal precipitation ranges from 0.2 to 2.5 mm/day for the default P50 scenario and the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario. The actual precipitation projections for the year 2100 lie in the range of 0.0 to 2.4 mm/day for default P50 scenario and the modified BAU P50 scenario. For the BCS P50 scenario and ECONOMY P50 scenario, projected seasonal precipitation for the year 2100 lies in the range of 0.0 to 2.3 mm/day.

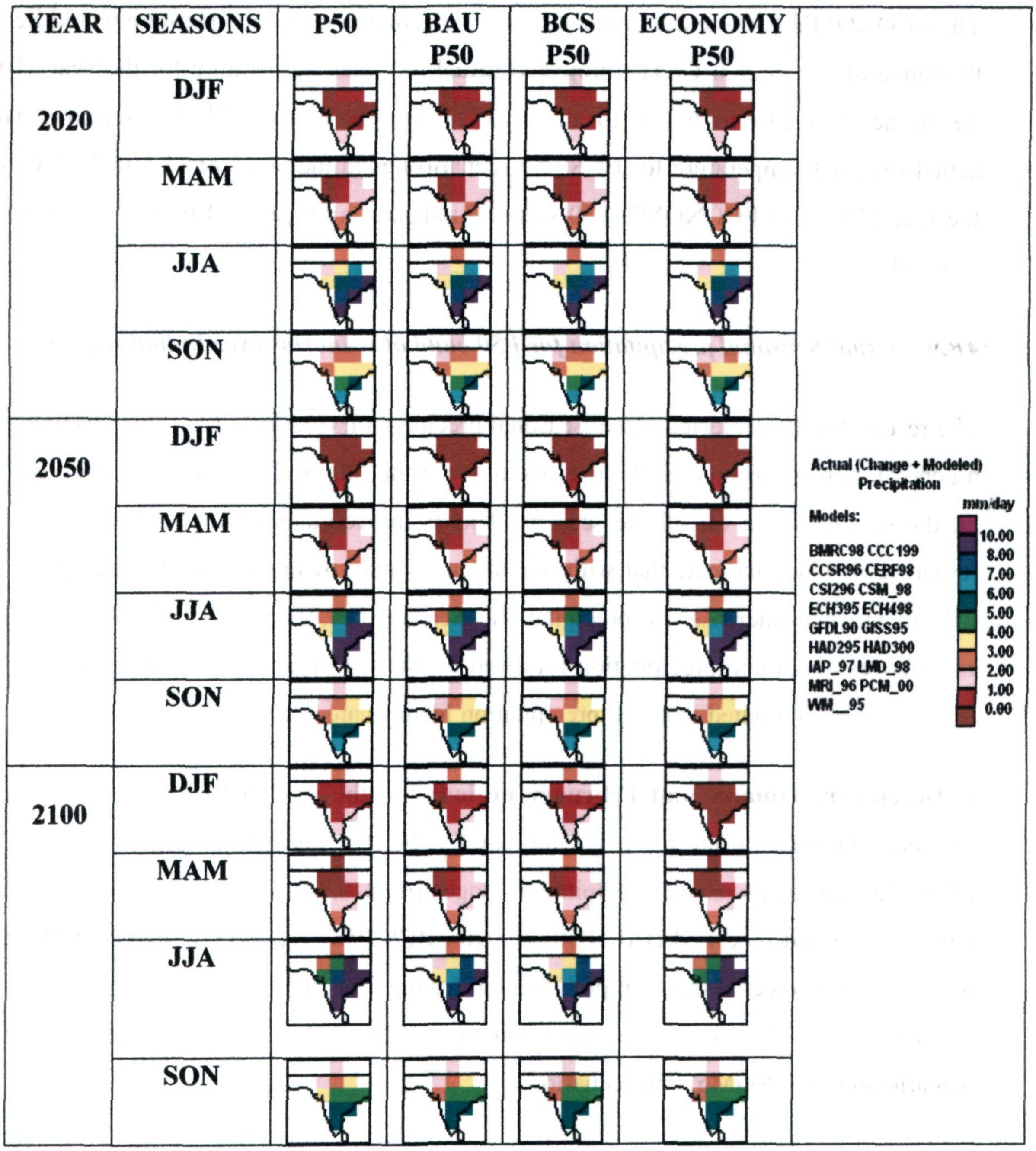

Figure 4.22 Actual seasonal precipitation (mm/day) for P50, BAU P50, BCS P50 and ECONOMY P50 scenarios over Indian region.

3. June, July and August period: For the year 2020, actual precipitation ranges from 1.7 to 8.5 mm/day for the P50 band of scenarios. For the year 2050, actual precipitation ranges from 2.1 to 9.1 mm/day for the default P50 scenario. For the modified scenarios BAU P50, BCS P50 and ECONOMY P50 actual precipitation ranges from 2.1 to 9.0 mm/day. The projected actual precipitation for the year 2100 lies in the range of 2.2 to 9.3 mm/day for default P50 scenario. For the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario actual precipitation for the year 2100 lies in the range of 2.1 to 9.2 mm/day.

4. September, October and November period: For the year 2020, actual precipitation ranges from 1.1 to 6.1 mm/day for the P50 band of scenarios. For the year 2050, actual precipitation projection ranges from 1.2 to 6.3 mm/day for the default P50 scenario, and for the modified scenarios BAU P50, BCS P50 and ECONOMY P50. The actual precipitation projections for the year 2100 lie in the range 1.2 to 6.0 mm/day for default P50 scenario. For the modified BAU P50 scenario, BCS P50 scenario and ECONOMY P50 scenario actual precipitation projection for the year 2100 lies in the range of 1.2 to 5.9 mm/day.

Chapter 5

Conclusions

The results of the simulations of MAGICC and SCENGEN model outputs have been discussed in the previous chapter-4 on 'Results and Discussion'. This chapter on 'Conclusions' summarizes the various results obtained mainly for the year 2100. This chapter is sub-divided in two sections. Section 5A deals with the results obtained for MAGICC outputs while section 5B covers the results obtained from SCENGEN model.

5A. Results of MAGICC Model

The salient findings obtained from MAGICC model simulations are given below:

1. For CO_2 emissions, default B1 scenario gives the lowest values of 6.4 PgC and default A2 scenario gives the highest value of 33.4 PgC in 2100.
2. Global CO_2 emissions from fossil fuels for the modified BAU scenarios range from 7.3 to 29.5 PgC, for modified BCS scenarios range from 6.7 to 28.9 PgC and for modified ECONOMY scenarios range from 7.2 to 29.4 PgC.
3. For CH_4 emissions, modified scenarios BAU B1, BCS B1 and ECONOMY B1 show the lowest value of 224.1 Tg and the default A2 scenario gives the highest value of 549.1 Tg for the year 2100.
4. Global CH_4 emissions for the modified BAU, BCS and ECONOMY scenarios range from 224.0 to 471.5 Tg.
5. For N_2O emissions, the modified scenarios BAU B1, BCS B1 and ECONOMY B1 give the lowest value of 5.3 TgN while default P50 scenario gives the highest value of 11.1 TgN in 2100.

6. Global N_2O emissions for the modified BAU, BCS and ECONOMY scenarios range from 6.8 to 9.8 TgN.
7. CO_2 concentration is lowest for modified scenario BCS B1 at 553.4 ppmv and highest for A2 scenario at 880.9 ppmv for the year 2100.
8. Global CO_2 concentrations for the modified BAU scenario ranges from 566.7 to 828.7 ppmv, for modified BCS scenario ranges from 553.4 to 813.5 ppmv and for modified ECONOMY scenario ranges from 560.9 to 822.0 ppmv.
9. CH_4 concentration is lowest for modified scenarios BAU B1, BCS B1 and ECONOMY B1 at 1902.5 ppbv and highest for P50 scenario at 2715.8 ppbv for the year 2100.
10. Global CH_4 concentrations for the modified BAU, BCS and ECONOMY scenarios range from 1902.5 to 2538.3 ppbv.
11. N_2O concentration is lowest for scenario B1 at 365 ppbv and highest for P50 scenario at 408.1 ppbv for the year 2100.
12. Global N_2O concentration for the modified BAU, BCS and ECONOMY scenarios range from 365.2 to 400.9 ppbv for the year 2100.
13. CO_2 radiative forcing value is lowest for modified scenario BCS B1 at 2.3 Wm^{-2} and highest for A2 scenario at 4.8 Wm^{-2} for the year 2100.
14. Global CO_2 radiative forcing for the modified BAU scenario ranges from 2.5 to 4.6 Wm^{-2}, for modified BCS scenario ranges from 2.4 to 4.5 Wm^{-2} and for modified ECONOMY scenario the global CO_2 radiative forcing range from 2.5 to 4.5 Wm^{-2}.
15. CH_4 radiative forcing value has been observed to be the lowest for modified scenarios BAU B1, BCS B1 and ECONOMY B1 at 0.1 Wm^{-2} and highest for P50 scenario at 0.4 Wm^{-2} for the year 2100.
16. Global CH_4 radiative forcing for the modified BAU, BCS and ECONOMY scenarios range from 0.1 to 0.3 Wm^{-2}.
17. N_2O radiative forcing value is lowest for B1 scenario at 0.2 Wm^{-2} and highest for P50 scenario at 0.3 Wm^{-2} for the year 2100.
18. Global N_2O radiative forcing for the modified BAU, BCS and ECONOMY scenarios range from 0.2 to 0.3 Wm^{-2}.
19. The temperature change when aerosol effect has been included is lowest for modified scenario BCS B1 at 2.1°C and highest at 2.9°C for P50 scenario.

20. Global mean temperature change (incorporating aerosol effects) for the modified BAU scenarios ranges from 2.2 to 2.8°C, for modified BCS scenario ranges from 2.1 to 2.8°C and for modified ECONOMY scenario ranges from 2.1 to 2.8°C.
21. The sea level change (incorporating aerosol effects) is projected to be lowest for modified scenario BCS B1 at 32.2 cm and highest at 38.5cm for P50 scenario for the year 2100.
22. Global mean sea-level change (incorporating aerosol effects) for the modified BAU scenario ranges from 32.8 to 37.0 cm, for modified BCS scenario ranges from 32.3 to 36.5 cm and for modified ECONOMY scenario ranges from 32.4 to 36.7 cm.
23. The temperature change (without incorporating aerosol effects) depicts the lowest value for modified ECONOMY B1 scenario at 1.7°C and highest at 3.0°C for A2 scenario.
24. Global mean temperature change (without incorporating aerosol effects) for the modified BAU scenario ranges from 1.7 to 2.9°C, for modified BCS scenario ranges from 1.7 to 2.8°C and for modified ECONOMY scenario ranges from 1.8 to 3.0°C for the year 2100.

5B. *Results of SCENGEN Model*

Simulation outputs from SCENGEN model provide outputs of changes in temperature and precipitation for the years 2020, 2050 and 2100. The results clearly indicate variations in the projected temperature and precipitation under various scenarios are summarized below.

1. For all the years, the change in annual mean temperature and change in precipitation observed for the default scenario are higher than the modified scenarios. The change in global mean annual temperature for modified scenarios lies in the range -0.3 to1.7°C, -0.1 to 4.1°C and 0.5 to 7.5°C, respectively for the years 2020, 2050 and 2100.
2. The global mean change in temperature is approximately 0.49°C for the year 2020, 1.30°C for the year 2050 and 2.78°C for the year 2100.

3. The temperature change from 2090-2099 relative to 1980-1999 ranges from 1.8 to 4.0°C as mentioned in the IPCC AR4 report. The result for the temperature change for the year 2100 relative to year 1990 as indicated by the study shows that P50 scenario run by AIM model provides a range of -0.1 to 3.9°C.
4. Global actual annual temperature for Asian region shows that the range of projected actual temperature may range from -17.8 to 27.8°C for the year 2020 and from -13.8 to 31.4°C for the year 2100.
5. The projected change in annual precipitation shows that the maximum percent change would be for Asian and African regions for all the years from 2020-2100. The projected average actual precipitation for global region would increase from 10.0 mm/day for the year 2020 to 10.7 mm/day in 2100.
6. For the change in annual mean temperature, the range for B2 band of scenarios is the highest and for the A2 band of scenarios is the lowest for the year 2050. For 2100, A2 band of scenarios show the lowest change in annual mean temperature and A1B band of scenarios show the highest change in annual mean temperature.
7. For the change in annual precipitation, the range for B1 band of scenarios is the highest and for the A2 band of scenarios is the lowest for the year 2050. For 2100, B1 band of scenarios show the lowest change in annual precipitation and A2 band of scenarios show the highest change in annual precipitation.
8. The model outputs for India capture the signature of Indian monsoon system.

5C. *Major findings*

The present study aimed to investigate the impacts of Indian GHG emission scenarios on the future global climate parameters using the MAGICC/SCENGEN 4.1 model obtained from CRU (UEA, Norwich, UK) and NCAR (Boulder, CO). The MAGICC model which provides the parameters pertaining to GHG emissions, GHG concentrations, radiative forcing, temperature and sea-level has the provision to allow modification in the global GHG emission inventories which provide inputs to the model runs. Taking the advantage of this provision, the global GHG emission inventories have been modified by incorporating three India specific GHG emission scenarios for the period 2000 to 2050 developed for BAU (Business-As-Usual), BCS (Best Case Scenario) and ECONOMY approaches. The BAU and BCS approaches are based on the fuel mix scenarios provided by the Planning Commission of India for fossil fuel consumption scenarios for India while Economy sector approach is based on the observed sectoral GDP growth rates witnessed in India.

The MAGICC output results of modified scenarios show impressible reduction in the projected GHG emissions for years 2050 and 2100. A mean reduction of 6.5 % has been observed in global CO_2 emissions from fossil fuel combustion for the year 2050, which increases to 9 % in 2100. Similarly, global CH_4 emissions from modified scenarios indicate a mean reduction of 13.6 % and 12.8 % respectively in the years 2050 and 2100. Global N_2O emissions show a reduction of about 15.9 % in 2050 and 15.6 % in 2100.

The mean per cent reduction in global CO_2 concentrations has been found to be 2.8 % in 2050 and 4.5 % in 2100. Similarly, the mean per cent reduction in CH_4 emissions varies from 4.8 % in 2050 to 4.0 % in 2100. Also, N_2O concentrations show a mean per cent reduction of 0.4 % in year 2050 and 1.0 % in year 2100.

Accordingly, a mean reduction of 7.5% in 2050 and 6.0% in 2100 was observed for CO_2 radiative forcing. CH_4 radiative forcing is observed to be reduced to 16.7% in 2050 and 13.8 % in 2100 and mean pre cent reduction in N_2O radiative forcing has been found to be 2.9 % in 2050 and 4.4 % in year 2100.

A reduction of 8.0 % in 2050 and 4.3 % in 2100 has been found in global annual mean temperature (incorporating full aerosol effects) and the resulting sea-level was found to have a reduction of 4.9 % and 3.4 % respectively for the years 2050 and 2100 compared to the values obtained from default emission scenario. The per cent reduction in global annual mean temperature has been found to be 6.6 % for 2050 and 4.9 % for 2100 when the aerosol effect have been kept constant at year post 1990 value.

The SCENGEN model, which takes MAGICC outputs as its inputs, provided the global values for change in annual global temperature and precipitation, actual annual temperature and precipitation, change in annual temperature and precipitation over Indian region, actual annual temperature and precipitation over Indian region, change in the seasonal temperature and precipitation over Indian region and actual seasonal temperature and precipitation over Indian region.

The results of the present work show that the country specific GHG emission inventories have large influence on the future scenarios of climate change parameters which is evident by the fact that the incorporation of India specific GHG emission scenarios resulted in the marginal reduction in the future projected climate change parameters.

5D. Scope for further work

In view of the significance of GHG emission inventories in determining the future projections of climate change parameters, it is important to mount efforts to generate accurate country specific GHG emission inventories to develop a more reliable global GHG emission database which can provide more realistic inputs to global climate models.

In India, the climate change modeling activities are confined to only a very few locations and, therefore, efforts are needed to build capacity at both individual levels and institutional levels for climate change modeling activities. It is important to generate capacity in India for assimilation of GHG emission inventories into climate change models.

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Appendix

Table 1. ESTIMATES OF CO_2 EMISSION FROM FOSSIL FUEL CONSUMPTION IN INDIA (PgC)

Year	BAU	BCS	ECONOMY
2000	0.5	0.5	0.5
2010	0.7	0.6	0.4
2020	1.0	0.8	0.6
2030	1.3	1.0	0.9
2040	1.7	1.2	1.3
2050	2.0	1.4	1.9

Table 2. ESTIMATES OF CH_4 EMISSION FROM FOSSIL FUEL CONSUMPTION IN INDIA (Tg)

Year	BAU	BCS	ECONOMY
2000	19.6	19.6	19.6
2010	20.6	20.6	20.6
2020	21.5	21.5	21.5
2030	21.5	21.5	21.5
2040	21.5	21.5	21.5
2050	21.5	21.5	21.5

Table 3. ESTIMATES OF N_2O EMISSION FROM FOSSIL FUEL CONSUMPTION IN INDIA (TgN)

Year	BAU	BCS	ECONOMY
2000	0.1	0.1	0.1
2010	0.2	0.2	0.2
2020	0.3	0.3	0.3
2030	0.3	0.3	0.3
2040	0.3	0.3	0.3
2050	0.3	0.3	0.3

Table 4. GLOBAL CARBON DIOXIDE EMISSIONS FROM FOSSIL FUEL COMBUSTION (PgC)

Year	DEFAULT GLOBAL EMISSION SCENARIO (PgC)					MODIFIED GLOBAL EMISSION SCENARIO (PgC)				
	P50	A1B-AIM	A2	B1	B2	P50 economy	A1B-AIM economy	A2 economy	B1 economy	B2 economy
2000	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
2010	8.4	9.7	9.3	8.5	8.5	7.3	8.4	8.1	7.4	7.5
2020	10.1	12.1	11.3	10.1	10.2	8.9	10.6	9.9	8.9	9.0
2030	12.1	14.0	13.7	11.5	11.8	10.8	12.4	12.1	10.3	10.6
2040	13.7	14.9	15.1	12.0	13.2	12.6	13.6	13.7	11.2	12.2
2050	15.4	16.0	16.6	12.6	15.0	14.6	15.1	15.6	12.3	14.2
2060	16.0	15.7	18.7	11.1	14.8	15.0	14.8	17.3	11.0	14.1
2070	16.6	15.4	21.2	9.9	14.7	15.6	14.6	19.3	10.0	14.0
2080	17.4	14.8	24.4	8.3	14.6	16.2	14.1	22.0	8.7	13.9
2090	17.7	13.9	29.6	7.3	14.2	16.5	13.4	26.2	7.9	13.6
2100	17.6	13.1	33.4	6.4	13.9	16.4	12.7	29.4	7.2	13.4

Year	MODIFIED GLOBAL SCENARIO EMISSIONS (PgC)									
	P50 BCS	A1B-AIM BCS	A2 BCS	B1 BCS	B2 BCS	P50 BAU	A1B-AIM BAU	A2 BAU	B1 BAU	B2 BAU
2000	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
2010	7.6	8.7	8.3	7.6	7.7	7.6	8.7	8.4	7.7	7.7
2020	9.1	10.8	10.1	9.1	9.2	9.3	11.0	10.3	9.3	9.4
2030	11.0	12.6	12.3	10.5	10.8	11.3	12.9	12.6	10.8	11.1
2040	12.5	13.5	13.6	11.1	12.1	12.9	14.0	14.1	11.5	12.6
2050	14.1	14.5	15.0	11.7	13.7	14.7	15.2	15.6	12.3	14.3
2060	14.5	14.3	16.8	10.5	13.6	15.1	14.9	17.4	11.1	14.2
2070	15.1	14.1	18.8	9.5	13.5	15.7	14.7	19.4	10.1	14.1
2080	15.7	13.6	21.4	8.2	13.4	16.3	14.2	22.1	8.8	14.0
2090	15.9	12.8	25.7	7.4	13.1	16.5	13.4	26.3	8.0	13.7
2100	15.8	12.2	28.9	6.7	12.8	16.4	12.8	29.5	7.3	13.4

Table 5. GLOBAL CARBON DIOXIDE EMISSION FROM DEFORESTATION (PgC)

Year	DEFAULT GLOBAL SCENARIO EMISSIONS				
	P50 (PgC)	**A1B-AIM (PgC)**	**A2 (PgC)**	**B1 (PgC)**	**B2 (PgC)**
2000	1.1	1.1	1.1	1.1	1.1
2010	1.2	0.9	0.9	0.9	1.0
2020	0.5	0.1	0.2	0.3	0.9
2030	0.5	0.0	-0.3	0.1	0.7
2040	0.4	0.3	-0.3	0.1	0.6
2050	0.4	0.6	-0.2	0.2	0.4
2060	0.3	0.7	-0.3	0.2	0.2
2070	0.3	0.9	-0.2	0.3	0.1
2080	0.4	1.0	-0.1	0.2	0.0
2090	0.4	1.0	-0.2	0.2	0.0
2100	0.4	1.0	-0.3	0.1	0.0

Table 7. GLOBAL NITROUS OXIDE EMISSIONS

Year	DEFAULT GLOBAL EMISSION SCENARIOS					MODIFIED (BAU, BCS, ECONOMY) GLOBAL EMISSION SCENARIO				
	P50 TgN	A1B-AIM TgN	A2 TgN	B1 TgN	B2 TgN	P50 TgN	A1B-AIM TgN	A2 TgN	B1 TgN	B2 TgN
2000	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
2010	7.4	7.0	7.3	6.9	7.1	6.3	6.0	6.2	5.9	6.1
2020	8.2	7.2	7.4	6.9	7.1	6.9	6.1	6.3	5.8	6.0
2030	8.8	7.3	7.6	6.8	7.3	7.4	6.2	6.4	5.8	6.1
2040	9.4	7.4	7.9	6.8	7.4	7.9	6.2	6.6	5.8	6.2
2050	9.9	7.4	8.1	6.8	7.5	8.3	6.3	6.9	5.7	6.4
2060	10.1	7.3	8.4	6.7	7.6	8.5	6.2	7.1	5.6	6.4
2070	10.3	7.2	8.8	6.6	7.7	8.6	6.1	7.4	5.6	6.5
2080	10.4	7.1	9.1	6.5	7.8	8.7	6.0	7.6	5.5	6.6
2090	10.8	7.1	9.5	6.3	7.9	9.0	6.0	7.9	5.4	6.7
2100	11.1	7.0	9.8	6.2	8.0	9.3	5.9	8.2	5.3	6.8

Table 8 GLOBAL CARBON DIOXIDE CONCENTRATIONS

Year	P50 (ppmv)	A1B (ppmv)	A2 (ppmv)	B1 (ppmv)	B2 (ppmv)	P50 BAU (ppmv)	A1B BAU (ppmv)	A2 BAU (ppmv)	B1 BAU (ppmv)	B2 BAU (ppmv)
2000	369.2	369.2	369.2	369.2	369.2	369.2	369.3	369.2	369.2	369.2
2010	389.7	392.8	391.4	389.7	389.8	387.3	389.9	388.7	387.3	387.4
2020	414.5	423.4	418.4	413.3	413.8	409.8	417.1	412.6	408.5	409.0
2030	444.3	458.4	450.0	438.6	441.0	437.4	448.8	441.3	431.9	434.1
2040	478.2	496.1	486.7	465.1	472.1	469.3	483.6	475.1	457.2	463.4
2050	516.1	535.8	528.1	492.7	508.0	505.1	520.9	513.8	484.4	497.6
2060	556.2	575.2	575.8	517.5	545.5	542.9	558.1	558.0	509.5	533.4
2070	597.0	612.4	631.7	536.5	581.4	580.9	593.3	608.5	529.7	567.5
2080	639.6	647.6	698.3	550.4	615.9	620.1	626.7	667.6	545.6	600.3
2090	683.7	679.8	779.9	559.7	648.8	660.5	657.5	740.5	557.5	631.7
2100	727.9	708.6	880.9	565.8	680.2	700.7	685.5	828.7	566.7	661.7

Year	P50 BCS (ppmv)	A1B BCS (ppmv)	A2 BCS (ppmv)	B1 BCS (ppmv)	B2 BCS (ppmv)	P50 economy (ppmv)	A1B economy (ppmv)	A2 economy (ppmv)	B1 economy (ppmv)	B2 economy (ppmv)
2000	369.2	369.3	369.2	369.2	369.2	369.2	369.2	369.2	369.2	369.2
2010	387.2	389.8	388.6	387.2	387.2	386.5	389.1	387.9	386.5	386.5
2020	409.2	416.5	412.0	408.2	408.3	407.7	415.0	410.5	406.4	406.8
2030	435.8	447.2	439.7	430.9	432.5	433.7	445.2	437.6	428.3	430.4
2040	466.3	480.6	472.1	454.7	460.4	464.4	478.7	470.2	452.3	458.5
2050	500.3	516.0	508.9	480.0	492.8	499.8	515.4	508.4	479.0	492.3
2060	536.0	551.2	551.1	503.2	526.6	537.5	552.7	552.6	504.2	528.1
2070	572.1	584.4	599.6	521.5	558.8	575.4	587.7	602.9	524.3	562.0
2080	609.4	615.9	656.7	535.6	589.7	614.4	620.9	661.7	540.1	594.6
2090	647.8	644.8	727.6	545.9	619.2	654.5	651.4	734.3	551.9	625.8
2100	686.1	670.9	813.5	553.4	647.3	694.4	679.2	822.0	560.9	655.5

Table 9 GLOBAL METHANE CONCENTRATIONS

Year	P50 (ppbv)	A1B (ppbv)	A2 (ppbv)	B1 (ppbv)	B2 (ppbv)	P50 BAU (ppbv)	A1B BAU (ppbv)	A2 BAU (ppbv)	B1 BAU (ppbv)	B2 BAU (ppbv)
2000	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4
2010	1861.2	1876.4	1867.1	1861.1	1861.9	1848.9	1862	1855.2	1850.1	1850.9
2020	1997.0	2030.3	1974.3	1981.1	1981.9	1956.6	1985.4	1941.2	1947.5	1948.2
2030	2158.4	2207.6	2069.2	2111.1	2118.1	2082.8	2127.5	2014.5	2051.2	2057.6
2040	2317.5	2338.1	2149.6	2225.7	2259.5	2207.7	2233.7	2076.9	2143.7	2172.5
2050	2461.8	2399.7	2210.2	2318.7	2399.1	2322.1	2285.5	2123.9	2220.2	2286.6
2060	2564.4	2382.3	2274.8	2364.3	2508.6	2404.6	2274.0	2174.2	2259.6	2376.7
2070	2628.9	2295.7	2353.0	2357.2	2579.5	2458.8	2207.3	2235.4	2257.5	2436.1
2080	2677.7	2185.9	2437.2	2234.1	2624.1	2501.8	2121.8	2301.5	2201.5	2474.6
2090	2708.5	2073.5	2520.4	2120.7	2641.1	2530.3	2033.7	2366.7	2071.1	2491.2
2100	2715.8	1970.1	2603.5	1911.2	2639.3	2538.3	1953.0	2431.8	1902.5	2493.2

Year	P50 BCS (ppbv)	A1B BCS (ppbv)	A2 BCS (ppbv)	B1 BCS (ppbv)	B2 BCS (ppbv)	P50 economy (ppbv)	A1B economy (ppbv)	A2 economy (ppbv)	B1 economy (ppbv)	B2 economy (ppbv)
2000	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4	1764.4
2010	1848.9	1862.0	1855.2	1850.1	1850.9	1848.9	1862.0	1855.2	1850.1	1850.9
2020	1956.6	1985.4	1941.2	1947.5	1948.2	1956.6	1985.4	1941.2	1947.5	1948.2
2030	2082.8	2127.5	2014.5	2051.2	2057.6	2082.8	2127.5	2014.5	2051.2	2057.6
2040	2207.7	2233.7	2076.9	2143.7	2172.5	2207.7	2233.7	2076.9	2143.7	2172.5
2050	2322.1	2285.5	2123.9	2220.2	2286.6	2322.1	2285.5	2123.9	2220.2	2286.6
2060	2404.6	2274.0	2174.2	2259.6	2376.7	2404.6	2274.0	2174.2	2259.6	2376.7
2070	2458.8	2207.3	2235.4	2257.5	2436.1	2458.8	2207.3	2235.4	2257.5	2436.1
2080	2501.8	2121.8	2301.5	2201.5	2474.6	2501.8	2121.8	2301.5	2201.5	2474.6
2090	2530.3	2033.7	2366.7	2071.1	2491.2	2530.3	2033.7	2366.7	2071.1	2491.2
2100	2538.3	1953.0	2431.8	1902.5	2493.2	2538.3	1953.0	2431.8	1902.5	2493.2

Table 10. GLOBAL NITROUS OXIDE CONCENTRATIONS

Year	P50 (ppbv)	A1B (ppbv)	A2 (ppbv)	B1 (ppbv)	B2 (ppbv)	P50 BAU (ppbv)	A1B BAU (ppbv)	A2 BAU (ppbv)	B1 BAU (ppbv)	B2 BAU (ppbv)
2000	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4
2010	324.4	324.3	324.5	324.1	324.3	324.5	324.2	324.5	324.1	324.3
2020	333.4	331.6	332.4	331.1	331.7	332.9	331.5	332.1	331	331.6
2030	342.7	338.7	339.8	337.3	338.6	341.7	338.3	339.3	337.2	338.3
2040	352.5	345.3	347.1	342.9	345.2	350.7	347.8	346.2	342.8	344.7
2050	362.7	351.5	354.3	348.0	351.5	359.9	350.7	353.0	347.9	350.7
2060	372.7	357.0	361.5	352.6	357.5	368.9	356.1	359.7	352.4	356.4
2070	382.1	361.1	368.7	356.5	363.1	377.4	360.8	366.4	356.3	361.8
2080	391.1	366.1	375.9	359.8	368.5	385.5	364.9	373.0	359.8	366.9
2090	399.8	369.8	383.2	362.7	373.7	393.2	368.6	379.6	362.7	371.7
2100	408.4	373.1	390.7	365.1	378.6	400.9	371.8	386.3	365.2	376.3

Year	P50 BCS (ppbv)	A1B BCS (ppbv)	A2 BCS (ppbv)	B1 BCS (ppbv)	B2 BCS (ppbv)	P50 economy (ppbv)	A1B economy (ppbv)	A2 economy (ppbv)	B1 economy (ppbv)	B2 economy (ppbv)
2000	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4	316.4
2010	324.5	324.2	324.5	324.1	324.3	324.5	324.2	324.5	324.1	324.3
2020	332.9	331.5	332.1	331.0	331.6	332.9	331.5	332.1	331.0	331.6
2030	341.7	338.3	339.3	337.2	338.3	341.7	338.3	339.3	337.2	338.3
2040	350.7	344.8	346.2	342.8	344.7	350.7	344.8	346.2	342.8	344.7
2050	359.9	350.7	353.0	347.9	350.7	359.9	350.7	353.0	347.9	350.7
2060	368.9	356.1	359.7	352.4	356.4	368.9	356.1	359.7	352.4	356.4
2070	377.4	360.8	366.4	356.3	361.8	377.4	360.8	366.4	356.3	361.8
2080	385.5	364.9	373	359.8	366.9	385.5	364.9	373.0	359.8	366.9
2090	393.2	368.6	379.6	362.7	371.7	393.2	368.6	379.6	362.7	371.7
2100	400.9	371.8	386.3	365.2	376.3	400.9	371.8	386.3	365.2	376.3

Table 11. GLOBAL CARBON DIOXIDE RADIATIVE FORCING

Year	P50 (W/m^2)	A1B (W/m^2)	A2 (W/m^2)	B1 (W/m^2)	B2 (W/m^2)	P50 BAU (W/m^2)	A1B BAU (W/m^2)	A2 BAU (W/m^2)	B1 BAU (W/m^2)	B2 BAU (W/m^2)
2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2010	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2020	0.9	1.0	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.8
2030	1.2	1.4	1.3	1.2	1.2	1.1	1.3	1.2	1.1	1.1
2040	1.6	1.8	1.7	1.5	1.5	1.5	1.7	1.6	1.4	1.4
2050	2.0	2.2	2.1	1.8	1.9	1.9	2.1	2.0	1.7	1.8
2060	2.4	2.6	2.6	2.0	2.3	2.3	2.4	2.4	2.0	2.2
2070	2.8	2.9	3.1	2.2	2.7	2.7	2.8	2.9	2.2	2.5
2080	3.2	3.2	3.6	2.4	3.0	3.0	3.1	3.4	2.3	2.8
2090	3.5	3.5	4.2	2.5	3.2	3.3	3.3	4.0	2.4	3.1
2100	3.9	3.7	4.9	2.5	3.5	3.7	3.5	4.6	2.5	3.4

Year	P50 BCS (W/m^2)	A1B BCS (W/m^2)	A2 BCS (W/m^2)	B1 BCS (W/m^2)	B2 BCS (W/m^2)	P50 economy (W/m^2)	A1B economy (W/m^2)	A2 economy (W/m^2)	B1 economy (W/m^2)	B2 economy (W/m^2)
2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2010	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
2020	0.8	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.7	0.7
2030	1.1	1.3	1.2	1.1	1.1	1.1	1.2	1.1	1.0	1.1
2040	1.5	1.6	1.5	1.3	1.4	1.5	1.6	1.5	1.3	1.4
2050	1.9	2.0	1.9	1.6	1.8	1.9	2.0	1.9	1.6	1.8
2060	2.2	2.4	2.4	1.9	2.1	2.2	2.4	2.4	1.9	2.1
2070	2.6	2.7	2.8	2.1	2.4	2.6	2.7	2.9	2.1	2.5
2080	2.9	3.0	3.3	2.2	2.7	3.0	3.0	3.4	2.3	2.8
2090	3.2	3.2	3.9	2.3	3.0	3.3	3.3	3.9	2.4	3.1
2100	3.5	3.4	4.5	2.4	3.2	3.6	3.5	4.5	2.5	3.3

Table 12. GLOBAL METHANE RADIATIVE FORCNG (W/m^2)

Year	P50 (W/m^2)	A1B (W/m^2)	A2 (W/m^2)	B1 (W/m^2)	B2 (W/m^2)	P50 BAU (W/m^2)	A1B BAU (W/m^2)	A2 BAU (W/m^2)	B1 BAU (W/m^2)	B2 BAU (W/m^2)
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2020	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2030	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1
2040	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2
2050	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2
2060	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
2070	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.3
2080	0.3	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.3
2090	0.4	0.1	0.3	0.2	0.3	0.3	0.1	0.2	0.1	0.3
2100	0.4	0.1	0.3	0.1	0.3	0.3	0.1	0.3	0.1	0.3

Year	P50 BCS (W/m^2)	A1B BCS (W/m^2)	A2 BCS (W/m^2)	B1 BCS (W/m^2)	B2 BCS (W/m^2)	P50 economy (W/m^2)	A1B economy (W/m^2)	A2 economy (W/m^2)	. B1 economy (W/m^2)	B2 economy (W/m^2)
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2020	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2030	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
2040	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2
2050	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2060	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
2070	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2
2080	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.3
2090	0.3	0.1	0.2	0.1	0.3	0.3	0.1	0.2	0.1	0.3
2100	0.3	0.1	0.3	0.1	0.3	0.3	0.1	0.3	0.1	0.3

Table 13. GLOBAL NITROUS OXIDE RADIATIVE FORCING

Year	P50 (W/m^2)	A1B (W/m^2)	A2 (W/m^2)	B1 (W/m^2)	B2 (W/m^2)	P50 BAU (W/m^2)	A1B BAU (W/m^2)	A2 BAU (W/m^2)	B1 BAU (W/m^2)	B2 BAU (W/m^2)
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2020	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2030	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2040	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2050	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
2060	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.1	0.1
2070	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2
2080	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2090	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
2100	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2

Year	P50 BCS (W/m^2)	A1B BCS (W/m^2)	A2 BCS (W/m^2)	B1 BCS (W/m^2)	B2 BCS (W/m^2)	P50 economy (W/m^2)	A1B economy (W/m^2)	A2 economy (W/m^2)	B1 economy (W/m^2)	B2 economy (W/m^2)
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2010	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2020	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2030	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2040	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2050	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
2060	0.2	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.1
2070	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.1	0.2
2080	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2090	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2
2100	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2

Table 14. CHANGE IN GLOBAL MEAN ANNUAL TEMPERATURE (°C)

Year	P50 (°C)	A1B-AIM (°C)	A2 (°C)	B1 (°C)	B2 (°C)	P50 BAU (°C)	A1B-AIM BAU (°C)	A2 BAU (°C)	B1 BAU (°C)	B2 BAU (°C)
2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2010	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2020	0.5	0.5	0.4	0.5	0.5	0.5	0.4	0.4	0.5	0.5
2030	0.8	0.8	0.6	0.7	0.8	0.7	0.7	0.5	0.6	0.8
2040	1.1	1.2	0.8	1.0	1.1	1.0	1.1	0.7	1.0	1.1
2050	1.4	1.5	1.0	1.4	1.5	1.3	1.4	0.9	1.3	1.4
2060	1.8	1.8	1.2	1.7	1.8	1.7	1.7	1.1	1.6	1.7
2070	2.1	2.2	1.4	1.9	2.0	2.0	2.0	1.3	1.8	2.0
2080	2.4	2.4	1.8	2.0	2.3	2.3	2.3	1.7	2.0	2.2
2090	2.7	2.6	2.3	2.1	2.5	2.6	2.5	2.1	2.1	2.4
2100	3.0	2.8	2.8	2.2	2.7	2.8	2.7	2.6	2.2	2.6

Year	P50 BCS (°C)	A1B-AIM BCS (°C)	A2 BCS (°C)	B1 BCS (°C)	B2 BCS (°C)	P50 economy (°C)	A1B-AIM economy (°C)	A2 economy (°C)	B1 economy (°C)	B2 economy (°C)
2000	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
2010	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2020	0.5	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.5
2030	0.7	0.7	0.5	0.6	0.7	0.7	0.7	0.5	0.6	0.7
2040	1.0	1.1	0.7	1.0	1.1	1.0	1.1	0.7	1.0	1.1
2050	1.3	1.4	0.9	1.3	1.4	1.3	1.4	0.9	1.3	1.4
2060	1.6	1.7	1.1	1.6	1.7	1.6	1.7	1.1	1.6	1.7
2070	1.9	2.0	1.3	1.8	1.9	2.0	2.0	1.3	1.8	1.9
2080	2.2	2.3	1.6	1.9	2.2	2.3	2.3	1.6	2.0	2.2
2090	2.5	2.4	2.1	2.0	2.4	2.5	2.5	2.1	2.1	2.4
2100	2.8	2.6	2.6	2.1	2.5	2.8	2.6	2.6	2.1	2.6

Table 15. CHANGE IN GLOBAL MEAN SEA LEVEL (cm)

Year	P50 (cm)	A1B-AIM (cm)	A2 (cm)	B1 (cm)	B2 (cm)	P50 BAU (cm)	A1B-AIM BAU (cm)	A2 BAU (cm)	B1 BAU (cm)	B2 BAU (cm)
2000	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
2010	3.6	3.5	3.5	3.6	3.6	3.6	3.5	3.5	3.6	3.5
2020	5.9	5.8	5.7	5.8	5.9	5.8	5.7	5.6	5.7	5.8
2030	8.6	8.6	8.0	8.4	8.7	8.4	8.3	7.8	8.2	8.5
2040	11.8	12.1	10.7	11.5	12.0	11.4	11.7	10.3	11.1	11.7
2050	15.5	16.1	13.6	15.2	15.8	14.9	15.4	13.0	14.7	15.3
2060	19.6	20.3	16.9	19.1	19.9	18.9	19.5	16.1	18.5	19.2
2070	24.1	24.8	20.4	22.9	24.1	23.2	23.8	19.4	22.3	23.3
2080	28.8	29.3	24.4	26.7	28.5	27.7	28.2	23.2	26.0	27.5
2090	33.6	33.7	29.2	30.2	32.8	32.3	32.4	27.7	29.5	31.8
2100	38.5	37.9	34.8	33.4	37.2	37.0	36.6	33.0	32.8	35.9

Year	P50 BCS (cm)	A1B-AIM BCS (cm)	A2 BCS (cm)	B1 BCS (cm)	B2 BCS (cm)	P50 economy (cm)	A1B-AIM economy (cm)	A2 economy (cm)	B1 economy (cm)	B2 economy (cm)
2000	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
2010	3.6	3.5	3.5	3.6	3.5	3.6	3.5	3.5	3.6	3.5
2020	5.8	5.6	5.6	5.7	5.8	5.8	5.6	5.5	5.7	5.8
2030	8.3	8.3	7.8	8.1	8.4	8.3	8.3	7.7	8.1	8.4
2040	11.4	11.6	10.2	11.1	11.6	11.3	11.5	10.1	11.0	11.5
2050	14.8	15.3	12.9	14.6	15.2	14.7	15.2	12.8	14.4	15.1
2060	18.7	19.3	15.9	18.3	19.0	19.7	19.2	15.8	18.2	19.0
2070	22.9	23.6	19.1	22.1	23.1	22.9	23.5	19.1	22.0	23.1
2080	27.4	27.8	22.8	25.7	27.2	27.4	27.9	22.9	25.7	27.2
2090	31.9	32.0	27.3	29.1	31.3	32.0	32.1	27.4	29.2	31.4
2100	36.5	36.1	32.5	32.3	35.4	36.7	36.3	32.6	32.4	35.6

Table 16. CHANGE IN GLOBAL MEAN ANNUAL TEMPERATURE (°C)

(SO_2 emissions constant after 2000)

Year	P50 (°C)	A1B-AIM (°C)	A2 (°C)	B1 (°C)	B2 (°C)	P50 BAU (°C)	A1B-AIM BAU (°C)	A2 BAU (°C)	B1 BAU (°C)	B2 BAU (°C)
2000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2010	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2020	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
2030	0.8	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.8
2040	1.1	1.2	1.1	1.0	1.0	1.1	1.1	1.1	1.0	1.0
2050	1.4	1.5	1.4	1.2	1.3	1.3	1.4	1.3	1.2	1.2
2060	1.7	1.7	1.7	1.4	1.5	1.6	1.6	1.6	1.4	1.5
2070	2.0	1.9	2.0	1.6	1.8	1.9	1.8	1.8	1.5	1.7
2080	2.3	2.1	2.3	1.7	2.0	2.1	2.0	2.1	1.6	1.9
2090	2.5	2.3	2.6	1.7	2.2	2.4	2.2	2.5	1.7	2.1
2100	2.8	2.4	3.0	1.8	2.4	2.6	2.3	2.9	1.7	2.3

Year	P50 BCS (°C)	A1B-AIM BCS (°C)	A2 BCS (°C)	B1 BCS (°C)	B2 BCS (°C)	P50 economy (°C)	A1B-AIM economy (°C)	A2 economy (°C)	B1 economy (°C)	B2 economy (°C)
2000	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
2010	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2020	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.5	0.5
2030	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7
2040	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0
2050	1.3	1.4	1.3	1.2	1.2	1.3	1.4	1.3	1.2	1.2
2060	1.6	1.6	1.5	1.3	1.4	1.6	1.6	1.5	1.3	1.4
2070	1.9	1.8	1.8	1.5	1.7	1.9	1.8	1.8	1.5	1.7
2080	2.1	2.0	2.1	1.6	1.9	2.1	2.0	2.1	1.6	1.9
2090	2.3	2.1	2.4	1.7	2.1	2.4	2.2	2.5	1.7	2.1
2100	2.6	2.3	2.8	1.7	2.2	2.6	2.3	2.8	1.7	2.3

Table 25. CHANGE IN SEASONAL TEMPERATURE AND SEASONAL PRECIPITATION FOR P50 BAND OF SCENARIOS FOR INDIAN REGION

SEASON	YEAR	SEASONAL TEMPERATURE CHANGE (°C)				SEASONAL PRECIPITATION CHANGE (%)			
		DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
DJF	2000	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	-20.0-3.9	-20.0-3.9	-20.0-3.9	-20.0-3.9
	2020	0.5-1.3	0.5-1.3	0.5-1.3	0.5-1.2	-83.1-(-)17.1	-83.1-(-)17.1	-83.1-(-)17.1	-83.1-(-)17.1
	2050	1.3-2.8	1.3-2.7	1.2-2.7	1.2-2.6	-99.3-127.0	-98.7-125.0	-98.7-124.9	-98.6-124.9
	2100	2.9-4.3	2.7-4.1	2.7-4.7	2.8-4.8	-60.1-178.6	-59.6-178.2	-59.5-178.1	-59.6-178.2
MAM	2000	0.2-0.3	0.2-0.3	0.2-0.3	0.2-0.3	-13.3-4.4	-13.3-4.4	-13.3-4.4	-13.3-4.4
	2020	0.5-1.1	0.5-1.1	0.5-1.1	0.5-1.1	-53.9-40.5	-53.9-40.2	-53.8-40.2	-53.8-40.1
	2050	1.5-3.0	1.4-2.8	1.4-2.8	1.4-2.8	-87.3-34.9	-87.1-34.7	-87.1-34.7	-87.1-34.6
	2100	3.0-4.7	2.9-4.4	2.8-4.3	2.8-4.4	-8.4-32.8	-7.9-31.1	-7.8-30.4	-7.9-30.8
JJA	2000	0.0-0.3	0.0-0.3	0.0-0.3	0.0-0.3	1.3-12.4	1.3-12.4	1.3-12.4	1.3-12.4
	2020	-0.2-0.9	-0.2-0.9	-0.2-0.9	-0.2-0.9	9.5-71.9	9.4-71.3	9.5-71.9	9.4-71.3
	2050	0.2-2.5	0.2-2.4	0.2-2.5	0.2-2.4	10.4-100.3	10.2-97.8	10.4-100.3	10.2-97.8
	2100	2.1-4.3	2.0-4.1	1.8-4.8	1.8-4.6	6.9-87.7	6.5-83.1	5.6-110.3	5.3-105.7
SON	2000	0.0-0.2	0.0-0.2	0.0-0.2	0.0-0.2	0.8-5.5	0.8-5.5	0.8-5.5	0.8-5.5
	2020	0.1-0.9	0.1-0.9	0.1-0.9	0.1-0.9	0.9-33.9	0.8-33.4	0.8-33.3	0.7-33.2
	2050	0.6-2.3	0.5-2.2	0.5-2.1	0.5-2.1	9.0-53.8	8.7-52.4	8.6-52.1	8.6-51.9
	2100	2.4-4.1	2.3-3.9	2.3-3.9	2.3-3.8	10.1-50.1	9.6-47.4	9.4-46.5	9.5-47.0

Table 26. ACTUAL SEASONAL TEMPERATURE AND PRECIPITATION FOR P50 BAND OF SCENARIOS FOR INDIAN REGION

SEASONS	YEAR	ACTUAL SEASONAL TEMPERATURE (°C)				ACTUAL SEASONAL PRECIPITATION (mm/day)			
		DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
DJF	2000	-5.2-24.9	-5.2-24.9	-5.2-24.9	-5.2-24.9	0.2-2.0	0.2-2.0	0.5-2.0	0.5-2.0
	2020	-4.4-25.2	-4.4-25.2	-4.4-25.2	-4.4-25.2	0.2-1.7	0.2-1.7	0.2-1.7	0.2-1.7
	2050	-2.8-26.1	-2.9-26.0	-3.0-26.0	-3.0-26.0	-0.2-1.6	-0.2-1.6	-0.2-1.6	-0.2-1.6
	2100	-0.5-27.7	-0.7-27.7	-0.8-27.5	-0.7-27.5	-0.6-1.6	-0.6-1.6	-0.6-1.6	-0.6-1.6
MAM	2000	6.6-31.1	6.6-31.1	6.6-31.1	6.6-31.1	0.3-2.2	0.3-2.2	0.3-2.2	0.3-2.2
	2020	7.3-31.7	7.3-31.6	7.3-31.6	7.3-31.6	0.3-2.4	0.3-2.4	0.3-2.4	0.3-2.4
	2050	9.2-32.8	9.0-32.7	9.0-32.7	9.0-32.7	0.2-2.5	0.2-2.5	0.2-2.5	0.2-2.5
	2100	10.9-34.5	10.7-34.3	11.6-34.5	11.7-34.5	0.0-2.4	0.0-2.4	0.0-2.3	0.0-2.3
JJA	2000	18.4-34.3	18.4-34.3	18.4-34.3	18.4-34.3	1.2-7.7	1.2-7.7	1.2-7.7	1.2-7.7
	2020	19.1-34.7	19.1-34.7	19.1-34.7	19.0-34.6	1.7-8.5	1.7-8.5	1.7-8.5	1.7-8.5
	2050	20.6-35.6	20.5-35.5	20.5-35.5	20.5-35.5	2.1-9.1	2.1-9.0	2.1-9.0	2.1-9.0
	2100	22.5-37.1	22.3-36.9	22.7-37.1	22.7-37.1	2.2-9.3	2.2-9.2	2.1-9.2	2.1-9.2
SON	2000	7.7-27.1	7.7-27.1	7.7-27.1	7.7-27.1	0.8-5.4	0.8-5.4	0.8-5.4	1.2-7.7
	2020	8.3-27.4	8.3-27.4	8.3-27.4	8.3-27.4	1.1-6.1	1.1-6.1	1.1-6.1	1.7-8.5
	2050	9.7-28.1	9.6-28.0	9.6-28.0	9.5-28.0	1.2-6.3	1.2-6.3	1.2-6.3	2.1-9.0
	2100	11.6-29.6	11.5-29.2	11.6-29.2	11.6-29.6	1.2-6.0	1.2-5.9	1.2-5.9	2.1-9.2

Table 17. CHANGE IN GLOBAL ANNUAL MEAN TEMPERATURE FOR P50 BAND OF SCENARIOS (°C)

REGION	2020				2050				2100			
	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
ASIA	0.4-1.3	0.4-1.2	0.4-1.2	0.4-1.2	1.1-3.5	0.9-3.2	0.9-3.2	0.9-3.2	2.4-6.6	2.3-5.8	2.3-5.7	2.3-5.7
AFRICA	0.4-1.2	0.4-1.2	0.4-1.1	0.4-1.1	1.2-2.7	1.2-2.6	1.2-2.6	1.2-2.6	2.6-4.6	2.6-4.3	2.4-4.2	2.4-4.2
AUSTRALIA	0.5-0.6	0.4-0.6	0.4-0.6	0.4-0.6	1.1-1.7	1.2-1.6	1.2-1.6	1.2-1.6	2.5-3.8	2.4-3.6	2.3-3.6	2.3-3.6
EUROPE	0.5-1.2	0.5-1.2	0.5-1.2	0.5-1.2	1.4-2.8	1.3-2.6	1.3-2.6	1.3-2.6	2.2-4.2	2.1-3.9	2.2-3.8	2.1-3.9
NORTH AMERICA	0.3-1.5	0.3-1.4	0.3-1.4	0.3-1.3	1.1-3.4	1.0-3.2	1.0-3.2	1.0-3.2	2.7-6.3	2.5-5.8	2.3-5.7	2.5-5.2
SOUTH AMERICA	0.1-0.7	0.2-0.7	0.1-0.7	0.1-0.7	0.5-2.0	0.4-1.7	0.4-1.7	0.4-1.7	1.5-3.8	1.4-3.6	1.4-3.5	1.4-3.5
GLOBAL	-0.3-1.8	-0.3-1.7	-0.3-1.7	-0.3-1.7	-0.1-4.4	-0.1-4.2	-0.1-4.1	-0.1-4.1	0.6-8.1	0.6-7.7	0.5-7.5	0.6-7.6
CHANGE IN GLOBAL MEAN TEMPERATURE	0.52	0.50	0.49	0.49	1.40	1.32	1.30	1.30	2.98	2.83	2.78	2.80

Table 18. ACTUAL ANNUAL GLOBAL MEAN TEMPERATURE FOR P50 BAND OF SCENARIOS (°C)

REGION	2020				2050				2100			
	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
ASIA	-17.7-27.9	-17.8-27.9	-17.8-27.8	-17.8-27.8	-16.1-29.3	-15.9-29.2	-16.3-29.2	-16.4-29.2	-13.4-31.7	-13.7-31.4	-13.8-31.4	-13.7-31.4
AFRICA	16.9-29.1	16.8-29.8	16.9-29.9	16.9-29.9	17.9-31.2	17.8-31.1	17.7-31.1	17.7-31.1	19.6-33.3	19.3-33.1	19.4-33.1	19.6-33.1
AUSTRALIA	14.0-27.5	13.9-27.5	13.9-27.5	13.9-27.5	14.7-28.5	14.6-28.4	14.6-28.4	14.6-28.8	16.1-30.4	15.9-30.2	15.9-30.2	15.9-30.2
EUROPE	-0.3-17.6	-0.4-17.5	-0.4-17.5	-0.4-17.5	1.0-18.8	0.9-18.7	0.9-18.9	0.9-18.7	2.7-28.5	2.5-20.6	2.4-20.5	2.5-20.5
NORTH AMERICA	-25.6-26.6	-25.6-26.1	-25.6-26.5	-25.6-26.1	-23.9-26.9	-24.1-26.8	-24.1-26.8	-24.1-26.8	-21.5-28.5	-21.6-28.4	-21.6-28.4	-21.6-28.4
SOUTH AMERICA	6.9-27.7	6.6-27.6	6.6-27.6	6.6-27.6	6.6-28.9	6.5-28.8	7.1-28.8	7.1-28.8	7.7-30.9	8.3-30.8	7.6-30.6	7.6-30.7
GLOBAL	-58.2-29.9	-58.3-29.9	-58.3-29.9	-58.3-29.9	-57.3-31.2	-57.4-31.1	-57.4-31.1	-57.4-31.1	-55.5-33.4	-55.6-33.1	-55.7-33.1	-55.7-33.1
CHANGE IN GLOBAL MEAN TEMPERATURE	0.52	0.50	0.49	0.49	1.40	1.32	1.30	1.30	2.98	2.83	2.78	2.80

Table 19. CHANGE IN GLOBAL ANNUAL PRECIPITATION FOR P50 BAND OF SCENARIOS (%)

REGION	2020				2050				2100			
	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
ASIA	-8.8-36.9	-8.6-35.8	-8.5-35.7	-8.5-35.5	-18.3-74.2	-17.6-71.2	-17.5-70.5	-12.4-70.3	-24.0-104.5	-23.8-114.0	-23.4-112.0	23.6-113.0
AFRICA	-15.6-35.0	-15.5-34.8	-15.5-33.9	-15.4-33.7	-21.9-18.0	-20.9-69.1	-20.7-71.5	20.6-68.2	-34.6-58.5	-29.3-105.9	-28.7-104.1	29.0-105.0
AUSTRALIA	-5.6-3.9	-5.1-4.0	-6.6-4.0	-5.1-4.0	-10.6-3.0	-10.0-3.0	-9.9-3.1	-9.8-3.1	-20.2-0.9	-15.9-3.5	-15.5-3.5	-15.7-3.5
EUROPE	-7.0-4.9	-6.7-4.8	-6.7-4.8	-6.6-4.7	-16.8-10.6	-16.0-10.0	-15.8-10.0	-15.7-10.0	-28.7-15.9	-28.0-18.4	-27.4-18.1	-22.7-18.3
NORTH AMERICA	-8.3-8.3	-8.6-7.9	-8.6-7.9	-8.6-7.8	-11.5-17.9	-11.3-17.5	-11.2-17.3	-11.2-17.2	-12.0-34.2	-13.6-34.4	-13.4-31.6	-13.5-34.1
SOUTH AMERICA	-9.0-7.1	-9.1-7.1	-9.1-7.1	-9.2-7.1	-16.2-9.8	-16.3-9.8	-16.3-9.9	-16.4-9.9	-18.0-15.9	-27.2-15.2	-20.7-14.9	-20.8-15.1
GLOBAL	-15.6-36.9	-15.5-35.8	-15.5-35.7	-15.4-35.5	-21.9-74.2	-20.9-71.2	-20.7-70.5	-20.6-70.3	-34.6-104.5	-29.3-114.0	-28.7-112.0	-29.0-113.0

Table 20. ACTUAL ANNUAL GLOBAL PRECIPITATION FOR P50 BAND OF SCENARIOS (mm/day)

REGION	2020				2050				2100			
	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50	DEFAULT P50	BAU P50	BCS P50	ECONOMY P50
ASIA	0.1-9.3	0.1-9.3	0.1-9.3	0.1-9.3	0.1-9.3	0.1-9.3	0.1-9.3	0.1-7.8	0.1-9.4	0.2-9.2	0.1-9.3	0.1-7.3
AFRICA	0.0-6.2	0.0-6.1	0.0-6.1	0.0-6.1	0.0-6.3	0.0-6.3	0.0-6.3	0.0-6.3	0.0-6.5	0.0-6.6	0.2-6.6	0.0-6.6
AUSTRALIA	0.5-4.6	0.5-4.6	0.5-4.6	0.5-4.6	0.5-4.5	0.5-4.5	0.5-4.5	0.5-4.5	0.5-4.5	0.4-4.4	0.4-3.7	0.4-4.4
EUROPE	0.9-3.2	0.9-3.2	0.9-3.2	0.9-3.2	0.8-3.4	0.8-3.4	0.8-3.4	0.8-3.4	0.7-3.5	0.7-3.6	0.9-3.2	0.9-3.2
NORTH AMERICA	0.2-4.5	0.2-4.3	0.2-4.5	0.2-4.3	0.2-4.5	0.2-4.7	0.2-4.5	0.2-4.7	0.2-4.8	0.3-4.9	0.2-4.7	0.2-4.9
SOUTH AMERICA	0.6-8.3	0.6-8.3	0.6-8.3	0.6-8.3	0.6-8.6	0.6-8.6	0.6-8.6	0.6-8.6	0.6-8.4	0.6-8.7	0.6-8.7	0.6-8.7
GLOBAL	0.0-10.0	0.0-10.0	0.0-10.0	0.0-10.0	0.0-9.7	0.0-9.7	0.0-9.7	0.0-9.7	0.0-11.1	0.0-10.7	0.0-10.7	0.0-10.7

Table 21. ANNUAL TEMPERATURE CHANGE FOR P50, A1B, A2, B1 AND B2 BAND OF SCENARIOS FOR INDIAN REGION

	Temperature Change (°C)											
	A1B AIM				A2 AIM				B1 AIM			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3
2020	0.3-0.9	0.3-0.7	0.3-0.7	0.3-0.8	0.3-0.8	0.3-0.7	0.3-0.7	0.3-0.7	0.3-0.8	0.3-0.8	0.3-0.8	0.3-0.8
2050	1.3-2.5	1.3-2.3	1.2-2.3	1.2-2.3	0.8-1.7	0.7-1.6	0.7-1.6	0.7-1.6	1.1-2.4	1.0-2.3	1.0-2.3	1.0-2.3
2100	2.3-4.7	2.2-4.6	2.1-4.5	2.1-4.5	2.6-4.6	2.4-4.3	2.4-4.2	2.4-4.3	1.7-3.8	1.7-3.8	1.6-3.7	1.6-3.7

	B2 AIM				*P50*			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3
2020	0.3-1.0	0.2-0.9	0.2-0.9	0.2-0.9	0.3-1.0	0.3-1.0	0.3-0.9	0.3-0.9
2050	1.1-2.6	1.1-2.5	1.0-2.4	1.0-2.4	1.0-2.6	0.9-2.5	0.9-2.4	0.9-2.4
2100	2.2-4.6	2.1-4.4	2.1-4.3	2.1-4.4	2.5-5.0	2.4-4.8	2.4-4.7	2.4-4.7

Table 22. ANNUAL PRECIPITATION CHANGE FOR P50, A1B, A2, B1 AND B2 BAND OF SCENARIOS FOR INDIAN REGION

	Precipitation Change (%)											
	A1B AIM				A2 AIM				B1 AIM			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.8-4.5	-0.4-3.6	-0.4-3.6	-0.4-3.6	-0.4-3.6
2020	2.1-24.5	2.0-24.1	2.0-24.0	2.0-23.9	3.4-24.2	3.3-23.8	3.3-23.7	3.3-23.6	-0.2-21.0	-0.3-20.7	-0.3-20.7	-0.4-20.6
2050	4.7-19.4	4.3-18.4	4.2-18.2	4.2-18.1	7.1-51.4	6.8-50.4	6.8-50.1	6.7-50.0	-7.3-28.9	-7.4-28.7	-7.6-28.1	-7.5-28.4
2100	-2.1-35.6	-2.5-34.6	-2.7-34.1	-2.6-34.3	13.3-58.6	12.6-56.2	12.4-55.6	12.5-55.9	-2.0-22.2	-2.2-21.6	-2.3-21.4	-2.3-21.3

	B2 AIM				P50			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	-0.3-3.4	-0.3-3.4	-0.3-3.4	-0.3-3.4	-0.4-3.6	-0.4-3.6	-0.4-3.6	-0.4-3.6
2020	-1.9-18.6	-2.1-18.3	-2.1-18.2	-2.1-18.2	-0.7-18.6	-0.8-18.3	-0.8-18.2	-0.8-18.2
2050	-1.5-22.5	-1.7-21.8	-1.8-20.2	-1.8-21.5	0.7-30.9	0.4-30.1	0.3-29.9	0.3-29.8
2100	-1.4-34.5	-1.9-33.4	-2.1-32.8	-2.0-33.1	2.3-38.5	1.8-36.9	1.6-36.3	1.7-36.6

Table 23. ACTUAL ANNUAL TEMPERATURE FOR P50, A1B, A2, B1 AND B2 BAND OF SCENARIOS FOR INDIAN REGION

	Actual Temperature (°C)											
	A1B AIM				A2 AIM				B1 AIM			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.4	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5
2020	7.5-27.7	7.4-27.6	7.4-27.6	7.4-27.6	7.3-27.7	7.3-27.7	7.3-27.7	7.3-27.7	7.4-27.7	7.4-27.6	7.4-27.6	7.4-27.6
2050	9.0-28.7	8.9-28.6	8.9-28.6	8.9-28.6	8.3-27.7	8.2-28.1	8.2-28.1	8.1-27.9	9.0-28.4	8.9-28.4	8.9-28.4	8.9-28.4
2100	11.3-29.8	11.2-29.5	11.1-29.6	11.2-29.5	11.2-30.0	10.9-29.8	10.8-29.7	10.8-29.8	10.4-29.1	10.4-29.1	9.2-29.0	9.3-29.0

	B2 AIM				P50			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5	6.9-27.5
2020	7.5-27.6	7.5-27.6	7.5-27.6	7.5-27.6	7.6-27.7	7.5-27.6	7.5-27.6	7.5-27.6
2050	8.7-28.3	9.1-28.4	9.0-28.4	9.0-28.4	9.2-28.4	9.0-28.3	9.0-28.3	9.0-28.3
2100	10.9-30.0	10.2-29.6	10.1-29.5	10.1-29.6	10.9-30.0	10.7-29.9	10.7-29.8	10.7-29.9

Table 24. ACTUAL ANNUAL PRECIPITATION FOR P50, A1B, A2, B1 AND B2 BAND OF SCENARIOS

	Actual Precipitation (mm/day)											
	A1B AIM				A2 AIM				B1 AIM			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	0.7-4.2	0.7-4.2	0.7-4.2	0.7-4.2	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1
2020	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5	0.9-4.5
2050	0.9-4.3	0.9-4.3	0.9-4.3	0.8-4.3	1.1-5.0	1.1-5.0	1.1-4.9	1.1-4.9	0.8-4.2	0.8-4.2	0.8-4.2	0.8-4.2
2100	0.8-4.1	0.8-4.1	0.8-4.1	0.8-4.1	1.1-4.9	1.1-4.9	1.1-4.9	1.1-4.9	0.7-3.9	0.7-3.9	0.7-3.9	0.7-3.9

	B2 AIM				P50			
YEAR	DEFAULT	BAU	BCS	ECONOMY	DEFAULT	BAU	BCS	ECONOMY
2000	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1	0.7-4.1
2020	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4
2050	0.8-4.1	0.8-4.1	0.8-4.1	0.8-4.1	0.9-4.4	0.9-4.4	0.9-4.4	0.9-4.4
2100	0.8-4.1	0.8-4.1	0.8-4.1	0.8-4.1	0.9-4.3	0.9-4.3	0.9-4.3	0.9-4.3